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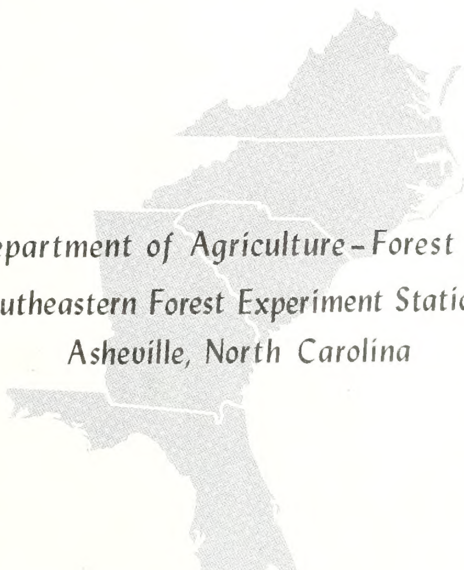

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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For too many years there has been relatively little interest in the regeneration of commercial hardwoods in the United States. Because of the rising emphasis on hardwood management, and following the success attained in regenerating conifers by direct seeding, foresters have recently begun to ask for information on inexpensive methods of hardwood regeneration and forestation. This paper reports the results of three direct seeding tests of oak, one in the upper Piedmont and two in the southern Appalachians of North Carolina.1/

Of the limited study results available on the direct seeding of oaks perhaps the most valuable is one by Korstian (1927), an intensive study of the factors affecting germination and survival of white and black oak groups. The work, done at Asheville, North Carolina, and New Haven, Connecticut, showed that up to 90 or 100 percent of the acorn crop may be destroyed by animals and insects. Field tests and observations indicated that screens were of little benefit in protecting acorns against rodents, and that a cover of leaf litter or soil was necessary for successful germination and survival of the acorns.

In a test in east-central Iowa, destruction of northern red oak acorns by rodents was severe on unprotected spots (Krajicek, 1955). Unprotected fall-sown acorns on the surface or in the leaf litter were almost completely destroyed, while those planted 1 inch deep, with litter replaced, were 68 percent destroyed. Acorns protected by screens were not eaten, but when the screens were removed in the spring, up to 75 percent of the germinated acorns were destroyed by rodents. Insects further reduced the survival to 5.6 percent.

Engle and Clark (1959) tested rodent repellents on red oak acorns in southern Indiana. Seeds were planted in the spring and fall of 1958 and spring of 1959 in a half-acre opening in an oak-hickory stand. Spring planting was with stratified nuts; depth of planting was 1 inch. Rodents were abundant. The repellents tested, Endrin and Thiram, failed to reduce rodent pilferage; in fact, untreated seeds produced more seedlings than

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1/ Grateful acknowledgement is due the Furniture, Plywood and Veneer Council of the N. C. Forestry Association for valuable assistance in the Piedmont study.

treated seeds. There was a striking difference between results for the 2 years; in the spring 1958 planting, 37 percent of the red oak survived, compared with 9 percent for the spring 1959 planting. There was a good hickory crop in 1957, but practically none in 1958.

The direct seeding of important bottomland oak species is being studied in South Carolina (Klawitter, 1959). Results indicate that seedlings from direct seeded acorns grow as well as or better than planted seedlings; 20 percent of the planted acorns survived as seedlings compared with 58 percent survival for planted seedlings. Clearing before seeding gave higher survival and growth rates than seeding under a residual stand with later release. Survival was lower on the wet areas than on the better-drained areas.

These study results point out some of the problems involved in direct seeding of acorns and indicate that the method does hold promise for regeneration of the oaks. There is need for more research to develop the best techniques for each species or species group in the varying conditions found in its range.

METHODS

Acorns of white oak (Quercus alba L.), black oak (Q. velutina Lam.), and northern red oak (Q. rubra L.) were collected during the fall of 1956 near Statesville, North Carolina, for the Piedmont study. Northern red oak acorns, the only species used in the two mountain studies, were collected at Bent Creek, near Asheville, North Carolina, during the fall of 1958 for the first study and during the fall of 1959 for the second study.

All acorns were immersed in water; those that floated were considered defective and were discarded. The remainder were treated with a hot water bath at 120° F. for 40 minutes for weevil control.

Piedmont

In the Piedmont study near Statesville, North Carolina, the white oak acorns were sown in the fall (fig. 1). The black and northern red oak acorns were stratified in moist sand in November, and the sprouted acorns were sown on March 26 the following spring. All acorns were planted three-fourths of an inch in mineral soil and the litter replaced.

Seeding was done on four different cover types to determine if rodent populations and acorn germination and survival varied by cover type. The following cover types were used:

1. Old field.
2. 4-year-old loblolly pine plantation.
3. Natural shortleaf-Virginia pine, poor site.
4. Hardwood, selectively cut, good site.

Figure 1.--Germinated white oak acorn, showing emerged radicle. Acorns of the white oak group germinate in the fall and overwinter in this stage.

Acorns were planted in paired seed spots. One spot of each pair was protected with one-fourth-inch mesh hardware cloth screening (fig. 2), and the other was left unprotected. Seed spots under forest cover types were located in small openings. The field design is illustrated below:

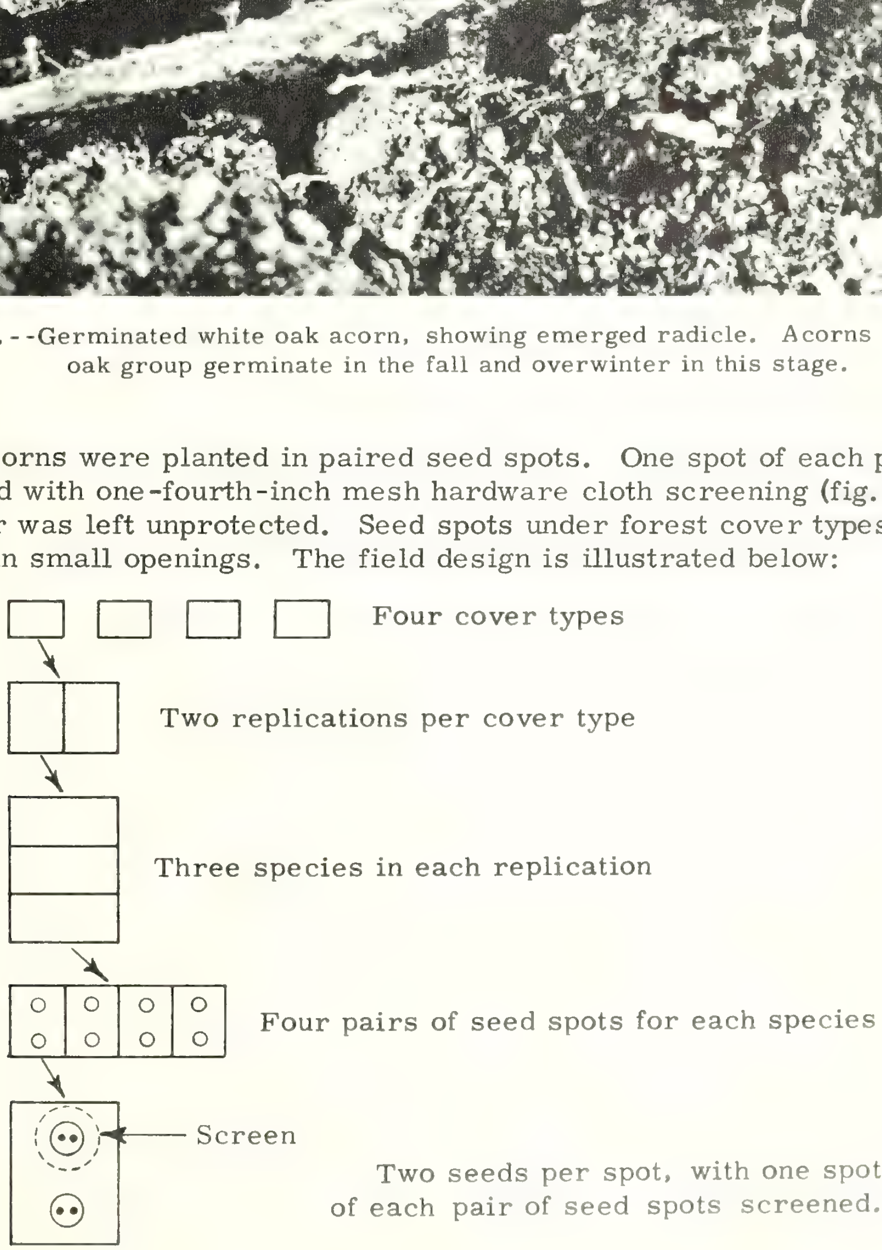

Figure 2.--Screen protection used in the Piedmont. No screened acorns were taken by animals in this study.

Traps baited with acorn cotyledons and peanut butter were used to sample the rodent population to determine some of the species that consume acorns. Trapping was done during a 48-hour period each month from October 1956 through April 1957. Animals were collected once each 24 hours during the 2-day period and preserved for identification.

Mountains

The first study at Bent Creek was installed in December 1958 and April 1959. Six treatments involving variation in time of sowing, depth of seed placement, and protection from predators were arranged in a Latin Square design. Treatment combinations were as follows:

Season	Planting Depth	Protection
Fall	Surface	No screens Screens
	1 to 2 inches	No screens Screens
Spring	Surface	No screens
	1 to 2 inches	No screens

In the second study, installed December 1959 and April 1960, screens were used in the spring as well as in the fall, making a total of eight treatment combinations for a complete factorial design. The treatments shown below were arranged in a randomized block field design with five replications.

Season	Planting Depth	Protection
Fall	Surface	No screens Screens
	1 to 2 inches	No screens Screens
Spring	Surface	No screens Screens
	1 to 2 inches	No screens Screens

In both studies, fall planting was done with unstratified acorns and spring planting was done with stratified, sprouted acorns. A treatment plot consisted of 16 acorns spaced 2 feet by 2 feet. Hardware cloth of one-fourth-inch mesh was used for screen protection (fig. 3). Survival counts were made during the first growing season following installation. Plantings were done in large openings in stands of yellow-poplar; a separate opening was used for each test. Screens were removed in April in the first test and on June 30 in the second test.

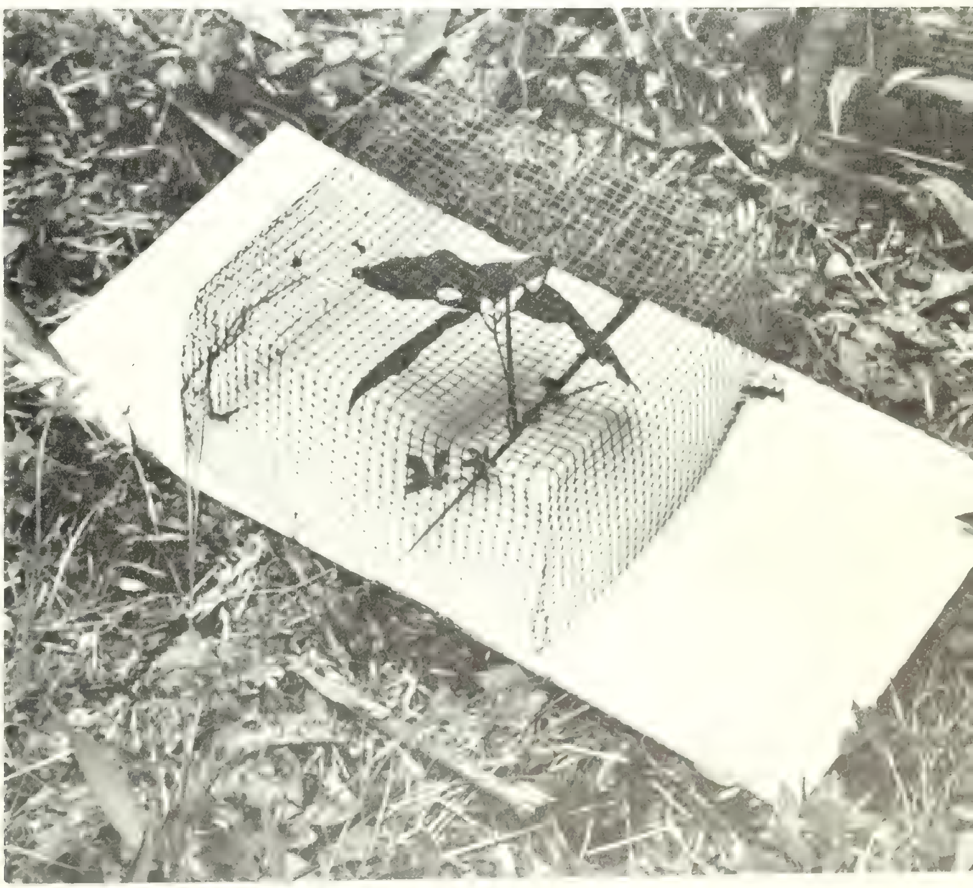

Figure 3.--A screen used in the mountain study. The white cards were used only for photographic purposes. Screens had no significant effect on seedling establishment in the mountain studies.

RESULTS

Piedmont

Screens were removed and a survival count was made on June 11, 1957. Only 37 out of 192, or 19 percent, of the exposed acorns had been eaten by animals, and none of the protected acorns were taken. There were no significant differences in rodent depredation associated with oak species or cover type. Analysis of the germination data as survival of individual plants and as percent of seed spots stocked revealed the following (table 1):

1. Northern red oak had the best individual acorn germination and the highest number of seed spots stocked, black oak was intermediate, and white oak ranked lowest.
2. Screen protection gave significantly higher individual plant survival, but did not result in a significant improvement in percent of seed spots stocked with at least one seedling.

A final inspection of the study was made on May 7, 1959, to determine subsequent survival (table 1). Mortality of northern red oak and black oak was three to four times greater than for white oak. White oak had the highest survival and percent stocking, black oak was intermediate, and northern red oak was lowest. This was the reverse of the species rankings two months after germination, and indicates the greater tolerance of white oak.

Several species of seed-eating animals were captured in the study area, but the whitefooted mouse (Peromyscus leucopus leucopus) appeared to be the most prevalent (table 2). Analysis of the trapping results indicated that the hardwood and old field habitats had higher rodent populations than the pine stands; however, populations appeared to be rather variable in all habitats.

Table 1. --Piedmont survival and seed spot stocking in June 1957 and May 1959 [1]

Date	White oak		Black oak		Northern red oak	
	Survival	Stocking [3]	Survival	Stocking	Survival	Stocking
	Percent					
PROTECTED SEED SPOTS [2]						
June 1957	56	88	78	94	95	100
May 1959	50	79	46	64	52	68
UNPROTECTED SEED SPOTS						
June 1957	53	72	58	75	82	100
May 1959	40	62	34	57	30	39
ALL SEED SPOTS						
June 1957	54	80	68	84	88	100
May 1959	45	71	40	61	41	54

1/ The 1959 data do not include one old-field replication and an additional old-field plot of white oak, which were destroyed in lake bed clearing.

2/ Data for all cover types were combined, since the effect of cover type on survival was not significant.

3/ Percent of seed spots containing at least one seedling.

Table 2. --Animals trapped on the Piedmont study area [1]

Common name	Scientific name	Total taken	Months taken
Shorttail shrew	Blarina brevicaudo carolinensis	3	October February March
Whitefooted mouse	Peromyscus leucopus leucopus	8	October November February April
Golden mouse	Peromyscus nuttalli	2	December April
Meadow vole	Microtus pennsylvanicus pennsylvanicus	4	October November January March
Eastern harvest mouse	Reithrodontomys humilis humilis	3	October November December
Pine mouse	Pitymys pinetorum pinetorum	2	February April
Field sparrow	Spizella pusilla pusilla	1	February
Total		23	

1/ Animal identifications were made by Dr. F. S. Barkelow, Head, Department of Zoology, North Carolina State College.

Mountain Study 1

Analyses of variance of survival revealed highly significant differences among treatments for each of the five examination dates (table 3). Sprouted acorns planted 1 to 2 inches deep in the spring gave better results during most of the first growing season than all other treatments. By September 16, however, survival for the treatment had dropped to the level of survival for acorns planted 1 to 2 inches deep under screens in the fall.

Screen protection did not significantly increase survival regardless of whether the fall-sown acorns were placed on the surface or planted 1 to 2 inches deep. Survival on May 29 was 51.0 percent and 46.9 percent, respectively, for screened vs. unscreened acorns planted in the soil, and was 1.0 percent and 2.1 percent, respectively, for screened vs. unscreened surface-sown acorns.

Treatments in which acorns were planted 1 to 2 inches deep gave better results than the treatments involving surface planting. Sprouted acorns sown on the surface in the spring gave significantly better early-season survival than acorns sown on the surface in the fall; the differences, however, had disappeared by the end of the season.

Table 3. --Average survival of northern red oak by date and treatment, Mountain Study 1

Season	Depth	Protection	Date of examination				
			May 7	May 29	June 22	July 17	Sept. 16
			Percent				
Fall	Surface	No screens	3.1	2.1	1.0	1.0	1.0
		Screens	1.0	1.0	3.1	4.2	3.1
	1 to 2 inches	No screens	38.5	46.9	41.7	40.6	31.2
		Screens	39.6	51.0	51.0	50.0	46.9
Spring	Surface	No screens	21.9	13.5	7.3	6.2	5.2
	1 to 2 inches	No screens	64.6	73.9	68.7	68.7	50.0

Only four whitefooted mice were captured during the limited amount of trapping done on the test site. No trapping was done during the dormant season. Observations indicated, however, that rodents were probably active during most of the winter and early spring. Many of the acorns on the surface under screens were taken by rodents that burrowed up from beneath. Browsing of the seedlings by deer resulted in slow growth and considerable mortality, causing at least part of the decline in survival during the summer.

Mountain Study 2

Screens were removed from all seed spots on June 30, and a survival count made (table 4). Tests of significance among survival means showed that spring planting 1 to 2 inches deep with screen protection was better than all other treatment combinations (100 percent survival), while sowing on the surface without screens in spring gave the poorest results (8.1 percent survival). Acorns which were fall-planted in the ground without screens had better survival than those which were fall-planted in the ground with screen protection; survival was, respectively 89.2 percent and 74.5 percent.

Table 4. --Average percent survival of northern red oak acorns, Mountain Study 2

Season	Depth	Protection	Average survival 1/
			Percent
Spring	1 to 2 inches	Screens	100.0
Fall	1 to 2 inches	No screens	89.2
Fall	1 to 2 inches	Screens	74.5
Spring	1 to 2 inches	No screens	68.9
Fall	Surface	No screens	23.4
Spring	Surface	Screens	22.7
Fall	Surface	Screens	18.9
Spring	Surface	No screens	8.1

1/ Survival means were compared by Duncan's Multiple Range Test. The means bracketed by any one line do not differ significantly at the 5-percent level of testing.

The survival values in table 4 represent the total effect of the different treatment combinations. Each of the eight treatments was some combination of the three factors tested--season of sowing, depth of sowing, and degree of protection. The study was so designed that the separate or "independent" effect of each factor could be determined, as well as the effect of holding any one factor constant while either or both of the other factors were varied. Thus it was possible to determine the average independent effect of

screens, for instance, or to determine the effect of screens in the fall vs. the effect of screens in spring, as another example.

Percent of seedling establishment is of primary interest in the study. However, in order to determine the fate of each acorn and thereby to understand more clearly the effect of each factor on survival, a tally of the rotten and missing acorns was made during the June 30 survival count (table 5). Analyses of the survival and the missing and rotten acorn data in table 5 were made to determine the effects of each of the three factors tested, as well as the interactions between and among them.

Table 5. --Percent of northern red oak acorns surviving, missing, or rotten on June 30, 1960, Mountain Study 2 1/

Season	Depth	Protection	Surviving	Missing	Rotten
			- - - - - -	Percent	- - - - - -
Fall	Surface	No screens	23.4	65.0	7.7
		Screens	18.9	0.5	79.0
	1 to 2 inches	No screens	89.2	0.3	8.3
		Screens	74.5	0.0	25.5
Spring	Surface	No screens	8.1	83.5	4.4
		Screens	22.7	0.3	66.5
	1 to 2 inches	No screens	68.9	17.2	3.6
		Screens	100.0	0.0	0.0

1/ The percentages do not always add to 100 because a few acorns were still present which were neither rotten nor established as seedlings.

SURVIVAL

Neither screens nor planting season had, on the average, a significant independent effect on seedling establishment. The average effect of screen protection was to increase survival by 1.8 percent (table 6, under "Effect mean," line "P"). Spring planting, as compared with fall planting, increased seedling establishment by only 0.1 percent on the average (table 6, under "Effect mean," line "S").

The effects of planting depth and the screen protection X planting season interaction were highly significant. The average effect of planting acorns 1 to 2 inches deep, as compared with surface sowing, was to increase seedling establishment by 48.9 percent. The interaction between screen protection and planting season is illustrated in two places in table 6. In the interaction values under "Season," line "P," are the values -5.1 percent, representing the effect of screens on survival of fall-planted acorns, and 8.7 percent, representing the effect of screens on survival of spring-planted acorns. That is, screens decreased survival of acorns planted in the fall by 5.1 percent, but increased survival of spring-planted acorns by 8.7 percent. The effect of spring planting in the presence and absence of screens is shown in the table, line "S,"

Table 6. --Factorial mean effects and interaction values for surviving, missing, and rotten acorns of northern red oak, Mountain Study 2

SURVIVAL

Factorial effect 1/	Effect mean	Screens		Depth		Season	
		Absent	Present	Surface	1 to 2 inches	Fall	Spring
	Percent	- - - - - - - - - - -	Interaction values (percent)	- - - - - - - - - - -			
P	1.8	-- 2/	--	1.4	2.2	-5.1	8.7
D	48.9**	48.5	49.3	--	--	47.8	50.0
S	0.1	-6.8	7.0	-1.0	1.2	--	--
PS	6.9**	--	--	5.3	8.5	--	--
MISSING ACORNS							
P	-33.0**	--	--	-46.2	-19.8	-30.7	-35.3
D	-17.6**	-30.8	-14.4	--	--	-17.8	-17.4
PD	13.2**	--	--	--	--	13.9	12.5
S	2.0**	4.3	-0.3	1.8	2.2	--	--
PS	-2.3**	--	--	-1.6	-3.0	--	--
ROTTEN ACORNS							
P	15.8**	--	--	29.8	1.8	17.2	14.4
D	-14.5**	-0.5	-28.5	--	--	-13.1	-15.9
PD	-14.0**	--	--	--	--	-13.1	-14.9
S	-4.0**	-2.6	-5.4	-2.7	-5.3	--	--

1/ P = Effect of screen protection.
D = Effect of planting 1 to 2 inches deep rather than on the surface.
S = Effect of planting in the spring rather than in the fall.
PD, PS = Interactions.

2/ Dashes occur where interactions are meaningless.

** Significant at the 1 percent probability level.

under "Screens." Spring planting gave 6.8 percent lower survival than fall planting when screens were not used, but when screens were used the effect of spring planting was to increase survival by 7.0 percent. Failure of screens to have the same effect in both planting seasons, and failure of spring planting to have the same effect in the presence or absence of screens, accounts for the highly significant screen X season interaction. The average interaction was 6.9 percent as shown in the "Effect mean" column of table 6.

Missing Acorns

All three factors--protection, planting depth, and season--had highly significant effects on the percent of acorns that were eaten or carried away by animals. Screen protection decreased the number of acorns taken by 33.0 percent. Planting 1 to 2 inches deep, as compared with surface sowing, gave a 17.6 percent decrease in acorn loss. Spring planting increased the number of acorns missing by 2.0 percent over that of fall planting (table 6).

Two highly-significant interactions were revealed by the analysis of missing acorn data. Screens decreased acorn loss by 46.2 percent when acorns were left on the surface, but only by 19.8 percent when they were planted 1 to 2 inches deep. In turn, planting 1 to 2 inches deep, as compared

with surface sowing, decreased loss by 30.8 percent when screens were absent and only by 14.4 percent when screens were used. Screens were less effective in fall than in spring, and more of the spring-planted acorns were taken from plots without screens than from those with screens.

Rotten Acorns

Screens increased the number of acorns that rotted by 15.8 percent, while planting 1 to 2 inches deep and spring sowing, respectively, decreased rotting by 14.5 percent and 4.0 percent (table 6). The interaction between screen protection and planting depth was highly significant. Screens increased acorn rotting by 29.8 percent when acorns were left on the surface, but only by 1.8 percent when acorns were planted 1 to 2 inches deep. Planting to a depth of 1 to 2 inches decreased rotting by 0.5 percent and 28.5 percent, respectively, when screens were absent or present.

DISCUSSION

It is clearly evident from these study results that direct-seeded acorns should be planted in the ground rather than merely placed on the surface. Uniformly good survival occurred in the Piedmont study in which all the acorns were planted in the soil. In the two mountain studies, planting depth proved to be the most important factor tested. It was the only factor which had a significant independent effect on seedling establishment in the second mountain study.

Spring planting in the ground had a definite advantage over fall planting in the ground, as well as a definite disadvantage. Only good, sprouted acorns were used in spring. The acorns which were planted in the fall had been immersed in water to separate the defective acorns, but since this method is not completely effective (Korstian, 1927), some of the fall-planted acorns very likely were defective. The disadvantage in spring planting was that the food supply is shortest at this time of year, resulting in greater predation pressure. Apparently the spring-planted acorns were easier to find than the fall-planted acorns during this period of low food supply, perhaps because of the freshly-disturbed spot of soil at each acorn. Soil disturbed in fall-planting had settled firmly into place and possibly had been covered by leaves and other litter. In Mountain Study 2, 17.2 percent of the acorns that were spring-planted 1 to 2 inches deep without screens were taken by animals, whereas only 0.3 percent of the acorns planted similarly in the fall were taken.

The effect of screens on seedling establishment was inconsistent in the three studies. Screens increased survival in the Piedmont study, but not in the two mountain studies. In Mountain Study 2, they decreased survival of acorns fall-planted in the ground. None of the screened acorns were taken by animals, and less than 1 percent of the unscreened ones were taken, but considerably more of the screened acorns rotted than did the unscreened ones. Perhaps the screens prevented leaves and other litter from accumulating on the protected spots. The mulching effect of litter on unscreened spots and the

lack of it on screened spots, even though both lots of acorns were planted in the ground, may have caused the difference in survival of the two lots of acorns.

Survival results showed that surface-sowing of acorns was an ineffective method of reproducing northern red oak; the missing and rotten acorn data revealed why. When acorns on the surface were not protected by screens many were taken by animals. When screens were used, however, the acorns were not taken, but rotted. In either case, survival was too low to be satisfactory.

SUMMARY

Results of three tests of direct seeding of oaks, one in the Piedmont and two in the mountains of North Carolina, indicate that white, northern red, and black oaks can be successfully regenerated by direct seeding. Best results were obtained with acorns that were planted in mineral soil. Screen protection, though effective, proved to be unnecessary in the Piedmont study where all the acorns were planted in the soil. In the mountain studies screens were ineffective; survival of acorns on the surface was very low regardless of screen protection, while results were good with acorns planted in the soil, whether screens were used or not. Acorns used for direct seeding should be treated for weevil control and planted 1 to 2 inches deep in mineral soil. Planting may be done either in the fall or in the spring.

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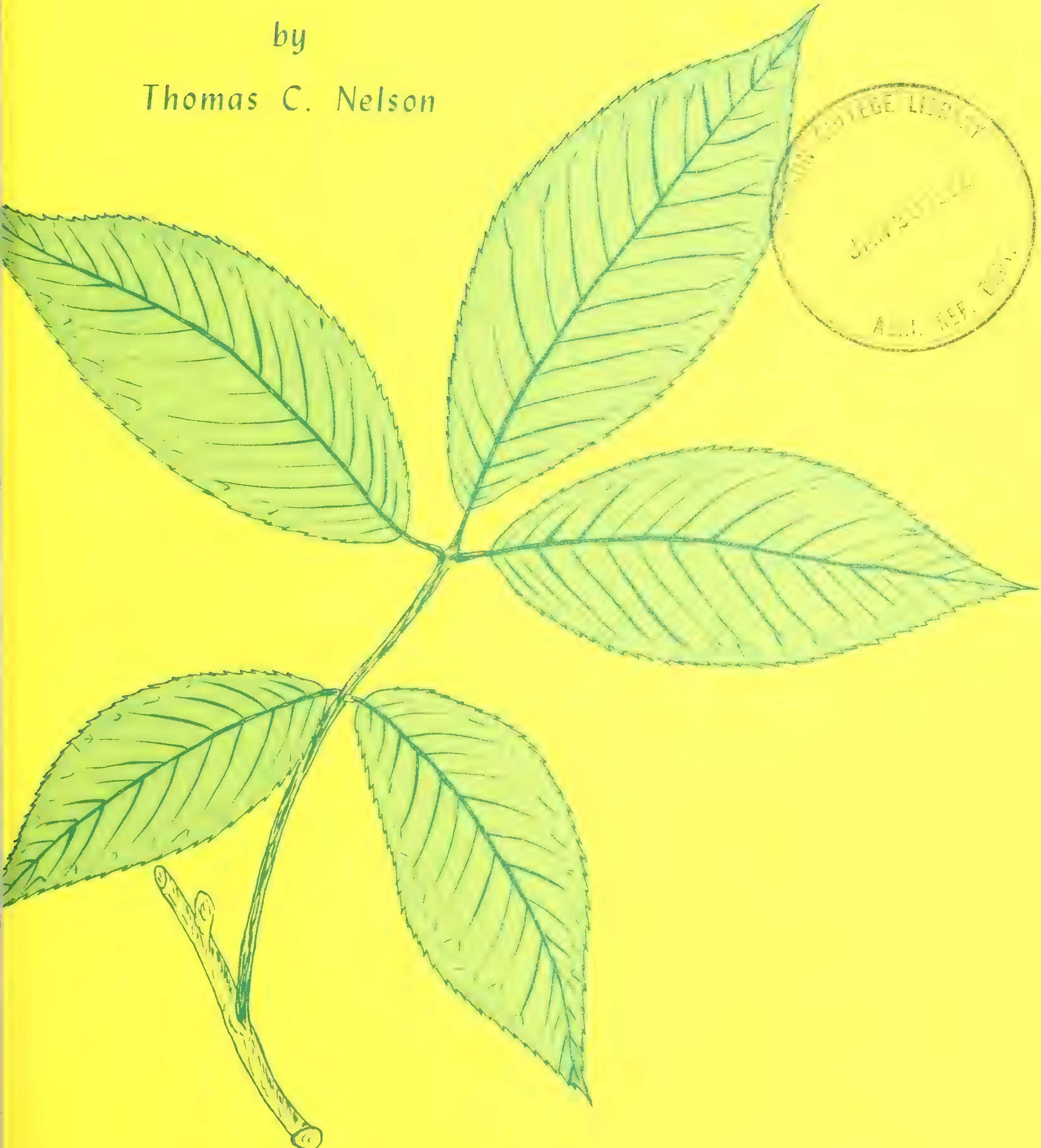
Silvical Characteristics of Shagbark Hickory

by

Thomas C. Nelson



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Silvical Characteristics of Shagbark Hickory

(Carya ovata (Mill.) K. Koch)

by

Thomas C. Nelson

Of all the hickories, shagbark (Carya ovata (Mill.) K. Koch) is probably the most distinctive in appearance because of its loose plates of bark. Common names include scalybark hickory, shellbark hickory, upland hickory, and shagbark. This species, as with most hickory species, loses its identity in the lumber market, and is sold as "hickory" (10). Shagbark is evenly distributed over a wide range, and together with pignut hickory furnishes the bulk of commercial hickory. The botanical range is shown in figure 1.

HABITAT CONDITIONS

CLIMATIC

Shagbark hickory grows in a humid climate, according to Thornthwaite's classification (15). Mean annual precipitation varies from 30 to 50 inches over most of the range, with 20 to 30 inches occurring during the growing season. Unusually heavy precipitation--80 inches or more--occurs in portions of the Southern Appalachians. Snowfall averages 50 inches per year in the northern portion of the tree's range and less than 1 inch in the southern portion. Variations in temperatures within its range are as follows (9):

Period	Temperature (Degrees F.)
Average annual	40 to 65
Average July	65 to 80
Average January	15 to 50
Recorded extreme	-40 to 115

The average growing season varies from 140 to 260 days.

EDAPHIC AND PHYSIOGRAPHIC

The site occupied by shagbark hickory varies greatly over its range. In the north, the species is found on upland slopes, while farther south, it is more prevalent on deep, moist soils of alluvial origin (7). Boisen and Newlin (4) report on its habitat in specific locations. In the Ohio Valley, shagbark grows chiefly on north and east slopes of fertile uplands; in the Cumberland Mountains, it is confined to the coves and to north and east slopes; and in Arkansas, Mississippi, and Louisiana, it grows principally on river bottoms (fig. 2).

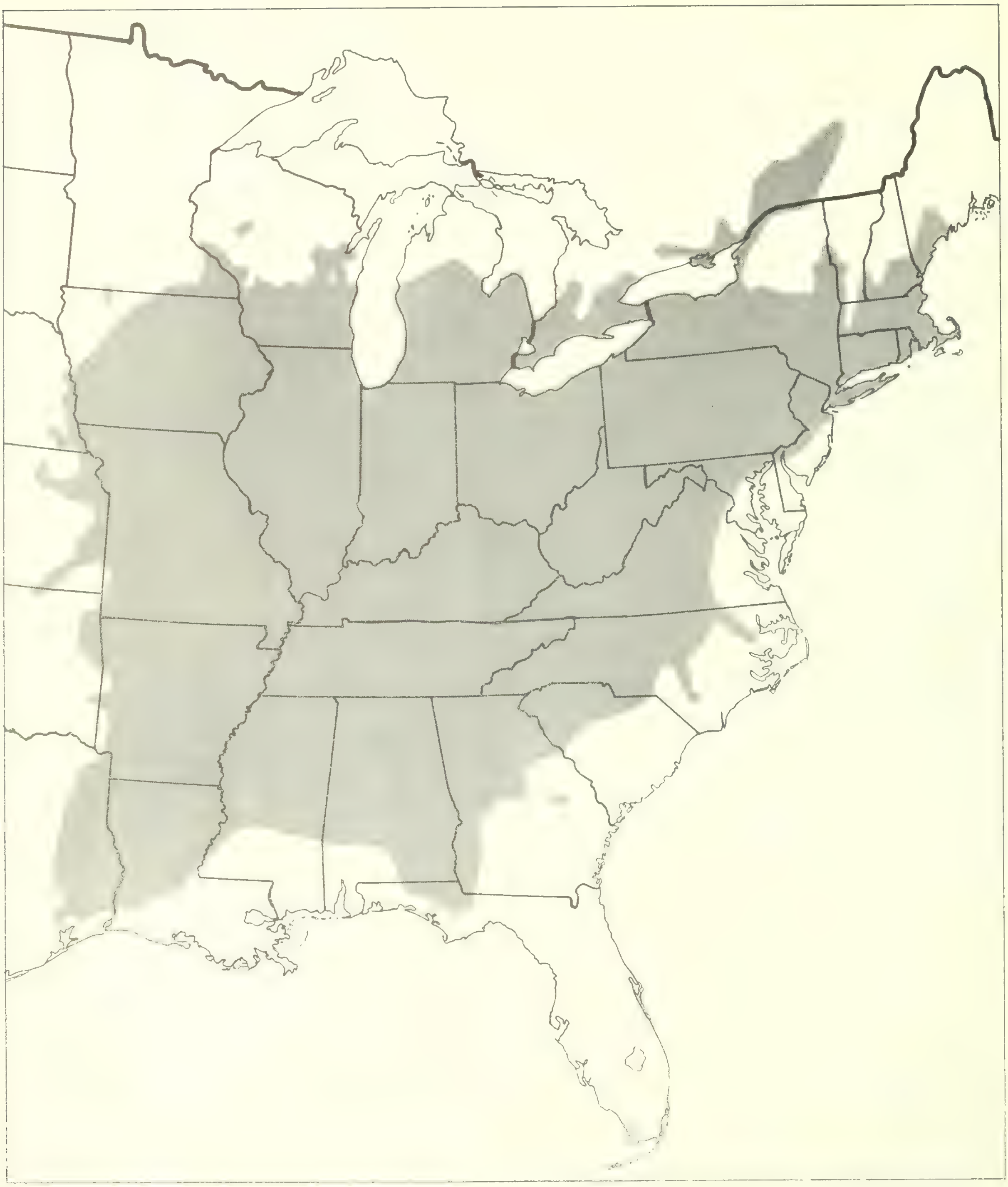

Figure 1. --Botanical range of shagbark hickory.

Figure 2.--Open-grown shagbark hickory, located near Parsons, West Virginia, in the Monongahela National Forest.

BIOTIC

In the northern part of its range, shagbark hickory is associated with oaks and other hickories, and in the south it is associated with bottomland hardwoods. Table 1 shows common associates for selected locations throughout its range. The Society of American Forester's Committee on Forest Types (13) lists shagbark as a component of the white oak-red oak-hickory, white oak, and swamp chestnut oak-cherrybark oak types.

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--Male and female flowers are borne in separate flowers on the same plant (monoecious). Male flowers are long, slender catkins occurring on new growth or near the summit of the previous season's growth. Female flowers are usually borne in two- to five-flowered spikes, approximately one-third inch in length and clothed with a dense, matted pubescence. Flowers open late in spring after the leaves are nearly full size, *i.e.*, in April or May (12).

Table 1.--Associates of shagbark hickory in selected sections of its range (5)

Region	Associated species
Cumberland Plateau	White oak (*Quercus alba*) Black oak (*Quercus velutina*) Mockernut hickory (*Carya tomentosa*) Yellow-poplar (*Liriodendron tulipifera*) Flowering dogwood (*Cornus florida*) Shortleaf pine (*Pinus echinata*) Pitch pine (*Pinus rigida*)
Nashville Basin	White oak Yellow-poplar Sugar maple (*Acer saccharinum*) American elm (*Ulmus americana*) Winged elm (*Ulmus alata*) Black walnut (*Juglans nigra*) Northern red oak (*Quercus rubra*) Chinkapin oak (*Quercus muehlenbergii*) Bur oak (*Quercus macrocarpa*) Blackgum (*Nyssa sylvatica*) Black cherry (*Prunus serotina*) Sweetgum (*Liquidambar styraciflua*) Sugarberry (*Celtis laevigata*)
Piedmont Lowland	White oak Northern red oak Black oak Mockernut hickory
Coastal Plain (West of Mississippi River)	White oak Chestnut oak (*Quercus prinus*) Southern red oak (*Quercus falcata*) Shumard oak (*Quercus shumardii*) Mockernut hickory Bitternut hickory (*Carya cordiformis*)

The fruit ripens in September and October and the seeds are dispersed from September through December (16) (fig. 3).

Seed production.--Shagbark reaches commercial seed-bearing age at 40 years. Optimum seed-bearing age is from 60 to 200 years and the maximum is 300 years. Good seed crops occur at 1- to 3-year intervals, and light seed crops are borne in intervening years (16). If the seed is fresh, 50 to 75 percent of the seed should germinate (14). Several species of nut insects reduce the germinative capacity of shagbark nuts; especially serious are *Conotrachelus affinis*, *Conotrachelus hicoriae*, and *Laspeyresia caryana*.

Shagbark hickory nuts are consumed as food by both humans and wildlife, but there is a very limited commercial market for the nuts. They are an important portion of the diet of red squirrel (*Sciurus hudsonicus*), eastern gray squirrel (*Sciurus carolinensis*), eastern fox squirrel (*Sciurus niger*), eastern chipmunk (*Tamias striatus*), and raccoon (*Procyon lotor*). Although the white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*) may consume some of the nuts, the vegetative parts probably are more important foods for these species of wildlife.

Seed dissemination.--Shagbark is a heavy-seeded species and averages 100 seeds per pound. Thus, seed dissemination is by gravity and by animals, principally squirrels.

VEGETATIVE REPRODUCTION

Shagbark hickory is a prolific sprouter. The relations of stump diameter to sprout production and sprout height are shown in table 2. As the stumps increase in size, the number of stumps that produce sprouts decrease, and the proportion of root suckers increases (4).

SEEDLING DEVELOPMENT

Establishment.--Hickories, in general, require a moderately moist seedbed for satisfactory seed germination and early establishment (17). There are also indications that stratification of hickory nuts at winter temperatures slightly above freezing aids germination (2).

Early growth.--Shagbark develops a long taproot early in life. Measurements of seedlings growing in heavy red clay soil showed that, at an age of 1 year, the average root length was about 12 inches.

SAPLING STAGE TO MATURITY

Growth and yield.--Shagbark hickory reaches heights of 130 to 140 feet and diameters of 20 to 30 inches in the Cumberland Mountains. In the bottomlands along the Mississippi River trees grow to larger diameters, but the maximum height growth is usually less than in the mountains. One characteristic of the tree is the tendency for the main stem to fork into two or three prongs at one-half to two-thirds the height of the tree (4).

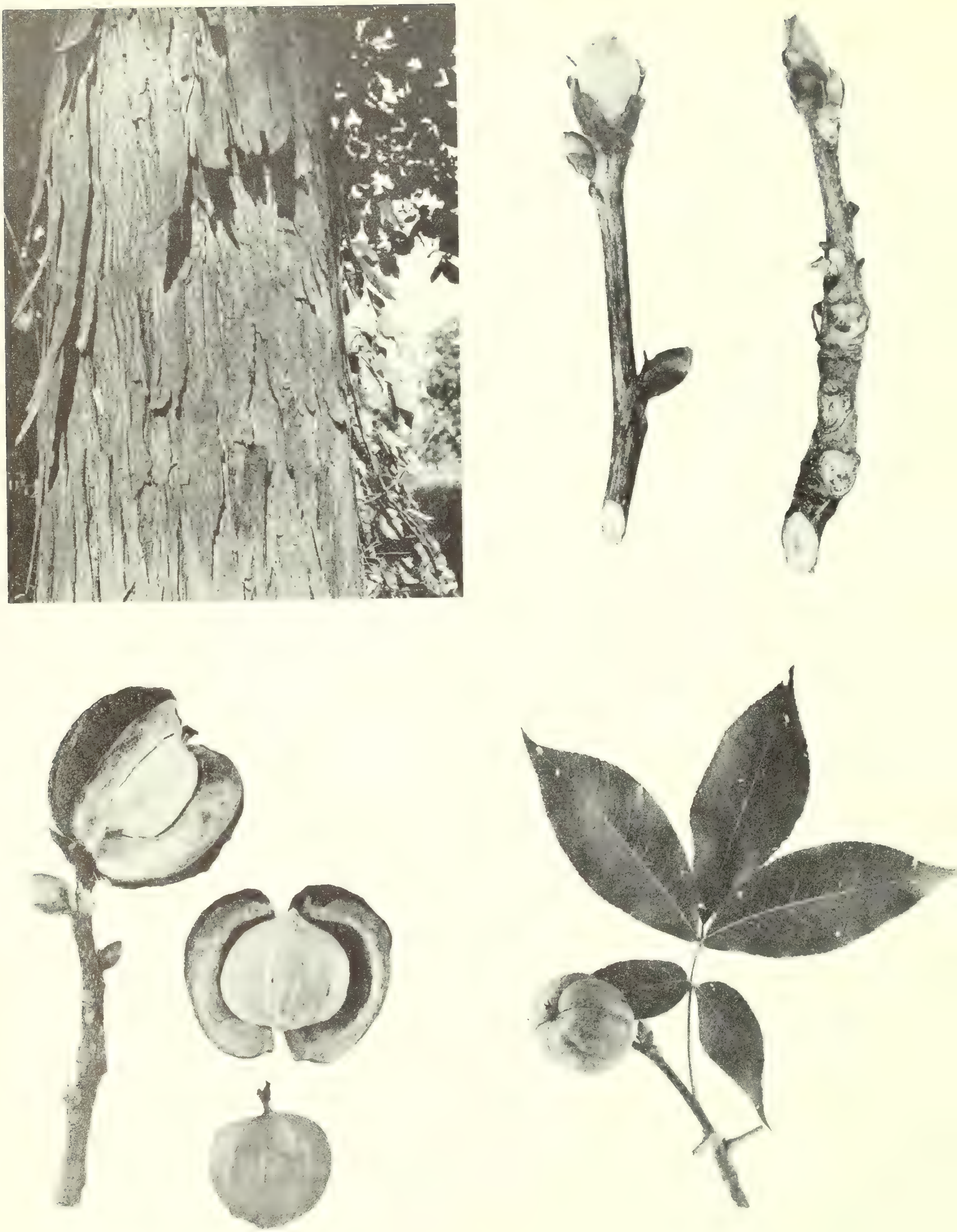

Figure 3.--Typical bark, twig and bud, fruit, and leaf of shagbark hickory.

Table 2.--Vigor and method of sprouting with increase in diameter of stump in shagbark hickory (4)

Diameter of stump (inches)	Stumps producing sprouts	Sprouts from stump	Sprouts from collar	Sprouts from root	Height of 1-year-old sprouts
	Percent				Feet
2	100	12	88	0	3.15
4	100	10	76	14	3.05
6	100	8	64	28	2.95
8	100	7	52	41	2.80
10	85	5	40	55	2.70
12	66	4	30	66	2.60
14	47	3	22	75	2.50
16	26	2	17	81	2.30

This species is one of the fastest-growing hickories, but it will produce only about one-fourth to one-half as much merchantable material as a white oak growing under the same conditions of soil and light. Representative growth data are shown in table 3 (4).

Reaction to competition.--Shagbark hickory is classified as moderately tolerant by Harlow and Harrar (7) (fig. 4). When released, suppressed hickories recover rapidly (4).

Shagbark hickory is usually a climax species in the timber types in which it occurs.

Principal enemies.--Shagbark hickory is very susceptible to damage by fire at all ages. Fire wounds allow entrance of heart rot fungi which cause progressive decay resulting in downgrading.

Leaf and twig diseases of the tree are numerous. However, there is little indication that they are factors in forest management. The most common are probably leaf blotch (*Mycosphaerella dendroides*), anthracnose (*Gnomonia caryae*), and witches' broom (*Microstroma juglandis*). *Poria spiculosa* is a common cause of rot in shagbark hickory, resulting in considerable cull and downgrade.

The species is attacked frequently by insects, although most references in the literature mention the genus *Carya* rather than shagbark itself. Hickory bark beetle (*Scolytus quadrispinosus*), however, probably causes considerable damage. Younger trees are particularly susceptible to attack by *Oncideres cingulatus*, *O. texanus*, and *O. pustulatus* (8).

Table 3.--Average growth rates of shagbark hickory in selected portions of its range (4)

Age (years)	Seedling growth				Coppice growth	
	D.b.h.	Height			D.b.h.	Height
	Indiana, Kentucky 1/	Ohio Valley 2/	Cumberland Mountains 2/	Mississippi Valley 2/	Indiana, Kentucky	Indiana, Kentucky
	Inches	- - - - - -	Feet	- - - - - - -	Inches	Feet
10	1.2	7	3	4	2.4	13
20	2.8	18	13	8	4.4	26
30	4.0	32	20	15	6.3	38
40	5.4	43	27	23	7.4	46
50	6.8	51	34	32	8.6	54
60	8.0	58	41	41	--	--
70	9.4	64	48	50	--	--
80	10.5	70	54	58	--	--
90	11.6	75	60	65	--	--
100	--	79	66	71	--	--
120	--	--	78	81	--	--
140	--	--	89	90	--	--
160	--	--	99	97	--	--
180	--	--	108	103	--	--
200	--	--	116	109	--	--

1/ Second growth.
2/ Virgin.

RACES AND HYBRIDS

There is no evidence so far to show races of shagbark hickory, but there are a number of varieties and hybrids. Carolina hickory, sometimes called southern shagbark hickory (Carya carolinae - septentrionalis (Ashe) Engl. & Graebn.), was combined with shagbark hickory in the 1953 Check List (10). It reaches commercial proportions in the Piedmont and ranges from central North Carolina to northern Georgia and northeastern Mississippi and west through eastern Tennessee (7). Bishop (3), discussing its distribution in Georgia, states that it is usually found in low, flat woods and river bottoms in the eastern Piedmont and mountains.

Bailey (1) recognizes three trade varieties of Carya ovata: var. Halesii, Hort.; var. Nuttalii, Sarg.; and var. fraxinifolia, Sarg.

Caldwell (6), studying natural variations of shagbark in central New York, found considerable diversity in morphological characteristics, the greatest occurring in the size, shape, and color of the nut, in the thickness of the shell, and in sweetness of the nutmeat.

Little (10) recognizes two hybrids of shagbark hickory: Carya X dunbarii Sarg. (Carya laciniosa x ovata) and Carya X laneyi Sarg. (Carya cordiformis x ovata). In addition, Richens (11) lists shagbark as crossing with pecan (Carya illinoensis).

Figure 4.--Forest-grown shagbark hickory, located in the George Washington National Forest, Virginia. Note the natural pruning which has taken place under forest conditions.

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Silvical Characteristics of White Basswood

by

James F. Renshaw

Station Paper No. 136

November 1961

U.S. Department of Agriculture
Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of White Basswood

(Tilia heterophylla, Vent.)

by

James F. Renshaw[1]

White basswood, Tilia heterophylla, Vent., is also called beetree linden, and sometimes wahoo (11). The species name indicates that its leaves take various forms, and as a result identification is difficult (6). In practice, white basswood is cut and mixed with other species of basswood, thus losing its identity in the lumber trade.

RANGE

White basswood is found from southern New York south along the Appalachian Mountains to Alabama, west to southern Indiana, and east of the mountains along the upper Piedmont Plateau in the Carolinas and Georgia to Jackson County, Florida (8) (fig. 1). It reaches its largest size in the Appalachian Mountain region where it is a characteristic tree in the overstory (3). It is much more common, however, in the mixed mesophytic forests of the Cumberlands, ranking next to sugar maple (Acer saccharum) in frequency of occurrence (3).

HABITAT CONDITIONS

CLIMATIC

White basswood occurs over a broad range of climatic conditions. Temperature extremes vary from almost frost-free winters in northwest Florida to the moderately severe winters of northern Pennsylvania and southern New York. Rainfall also varies widely, ranging from more than 80 inches for limited areas in the Southern Appalachians (14) to a low of about 30 inches. For its best development, however, the species requires abundant rainfall during the growing season. It will withstand short periods of zero weather in the winter and 100-degree weather in the summer.

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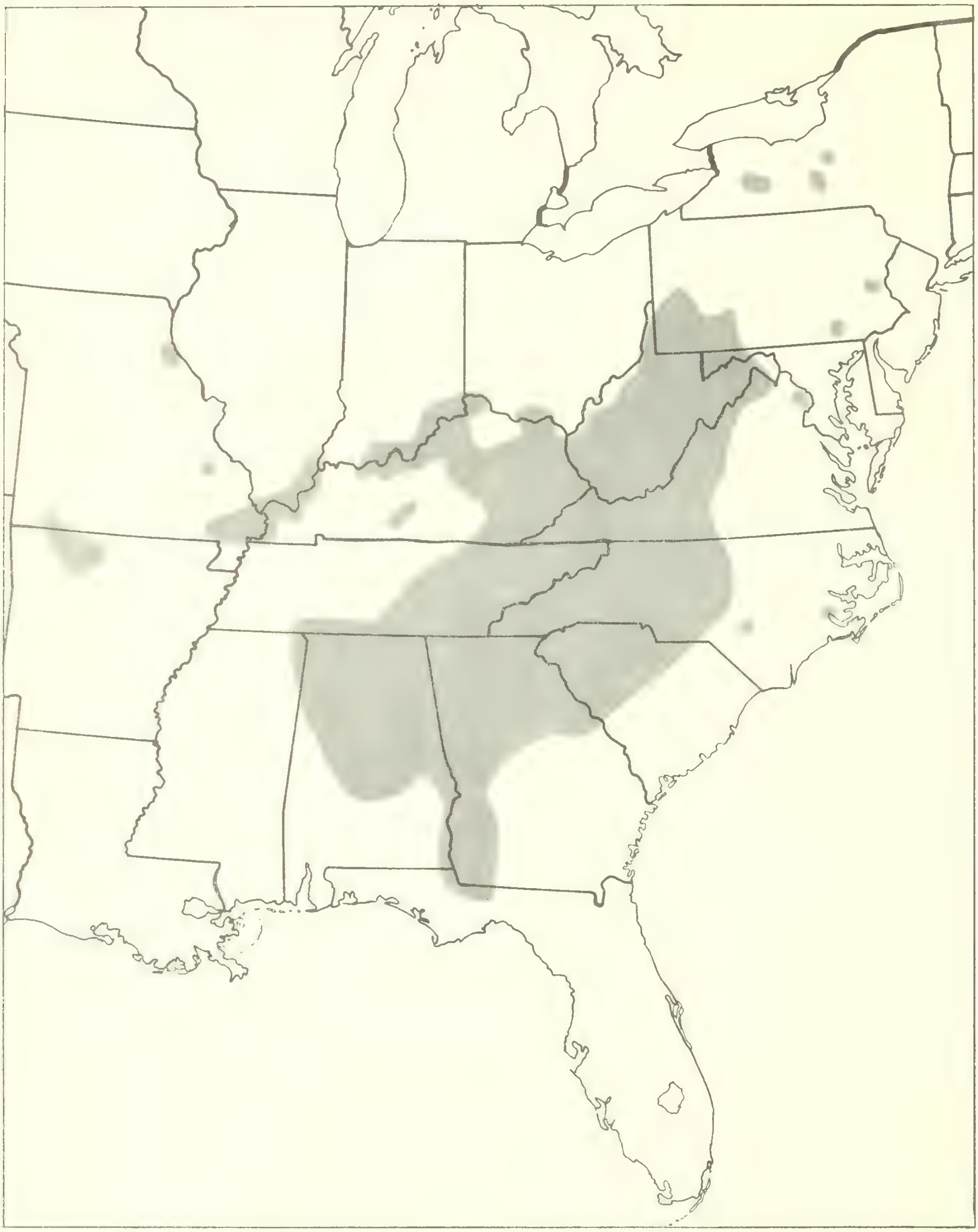


Figure 1. --Botanical range of white basswood.

EDAPHIC

Quite particular in its soil and moisture requirements, white basswood cannot tolerate very wet or very dry conditions, and is almost always found on moist but well-drained soils. Ideal growing conditions are found along mountain streams or in mountain coves where the soils have either an alluvial or colluvial origin. These soils are deep and friable and contain considerable humus (3).

PHYSIOGRAPHIC

The species occurs within a wide range of altitudinal limits, and although rare at very low elevations (6), it is occasionally found in the coastal plain. It becomes more common in the upper Piedmont near the mountains, but is most common in the Appalachian Mountains at elevations between 3,000 and 5,000 feet, where it is usually found on north and east exposures. Ample moisture and adequate drainage are the principal controlling factors in its occurrence--as is the case with yellow-poplar.

BIOTIC

Although basswood is listed as a component of 16 of the 106 cover types listed for North America (13), white basswood is found in only half of them. It is a major species in only one of these types, northern red oak-basswood-white ash. In the northern part of its range it occurs with northern red oak (*Quercus rubra*), white ash (*Fraxinus americana*), black cherry (*Prunus serotina*), white oak (*Quercus alba*), sweet birch (*Betula lenta*), butternut (*Juglans cinerea*), American elm (*Ulmus americana*), and eastern hemlock (*Tsuga canadensis*); farther south in the Appalachians it is more commonly found with yellow buckeye (*Aesculus octandra*), yellow birch (*Betula alleghaniensis*), sweet birch, sugar maple (*Acer saccharum*), black cherry, and yellow-poplar (*Liriodendron tulipifera*).

Baker (1) classes all basswood as tolerant. No variations between species are noted. Braun (3) lists white basswood as a major species in the climax mesophytic forests.

LIFE HISTORY

SEEDING HABITS

White basswood flowers in early summer (12). Bees, attracted by its high degree of fragrance, make a very choice honey from its large quantities of nectar. The fruits are nut-like, $\frac{1}{4}$- to $\frac{3}{8}$-inch in diameter. Each cluster of a half dozen or so seeds is furnished with a special seed-leaf (10); this leaf serves as a parachute and retards descent so that the wind has an opportunity to carry the seeds some distance before they strike the ground. Little information exists about the flowering and fruiting of this species, but is con-

sidered similar to American basswood (Tilia americana), which flowers in June and July and ripens in September and October, with seedfall the following winter and spring (15).

As with most tree seeds, natural germination is best on mineral soil. No specific information is available for this species. In general, basswood seeds may remain dormant for several years (15).

VEGETATIVE REPRODUCTION

White basswood sprouts vigorously and is commonly found growing in clumps of from three to six or more stems. Although clump growth and development is quite good, the trees are frequently very defective and quite susceptible to sleet or wind damage. Sprout stands are therefore less desirable than those of seedling origin.

GROWTH AND MATURITY

Mature white basswood grows to a height of more than 90 feet, and to a diameter of more than 3 feet (4). The bole is typically free of branches and is relatively cylindrical in shape. According to Campbell (5), the basswoods are intermediate in their growth rate when compared with other Southern Appalachian species, growing faster than most of the oaks and maples, but considerably slower than yellow-poplar or northern red oak. He shows that it reaches economic maturity for sawtimber at 17 to 24 inches d.b.h., the size depending on the vigor class of the tree.

Principal enemies.--White basswood is relatively free of serious diseases, although it is attacked by cankers, rots, stains, leaf spots, and wilt. Discolorations of the wood are common following wounding of any type, but are not considered serious unless decay enters before the wound heals over. Decay fungi attacking white basswood include species of Daedalea, Fomes, Hydnum, and Pholiota (2). Basswoods of stump-sprout origin or seedlings that have been wounded are likely to become highly defective; often the main bole of such trees will be almost entirely hollow (9).

Cankers caused by Nectria galligena are common on basswood but are not considered serious. Leaf spots are common but do not cause excessive damage. The common leaf spots are caused by species of Cercospora, Phyllosticta, and Gloeosporium. Wilt caused by a species of Verticillium is known to occur on white basswood but so far has been of no consequence in forest stands (16).

White basswood is also comparatively free of serious insect enemies (7). It is host, however, to many defoliators, several borers, aphids, and gall midges. Common defoliators include the basswood leaf roller (Pantographa limata), the snow-white linden moth (elm spanworm) (Ennomos subsignarius), the linden looper (Erannis tiliaria), the white-marked tussock moth (Hemerocampa leucostigma), the variable oak leaf caterpillar (Hetero-

campa manteo), a leaf miner (Baliosus ruber), and the linden leaf beetle (Calligrapha scalaris).

Important borers include the linden borer (Saperda vestita), which attacks in the cambium area, and a flat headed borer (Chalcophora campestris), which enters the wood at wounds.

As in yellow-poplar, the tender, tasty twigs and smaller branches of basswood are eagerly browsed by livestock and white-tailed deer (Odocoileus virginianus).

Because of its thin bark, basswood is very susceptible to fire damage, especially at seedling and sapling size (fig. 2). Consequently, butt rot is very common and serious in burned stands. Basswood (Tilia spp.) had the highest cull percent in all diameters of any species studied by Hepting and Hedgcock (9).

SPECIAL FEATURES

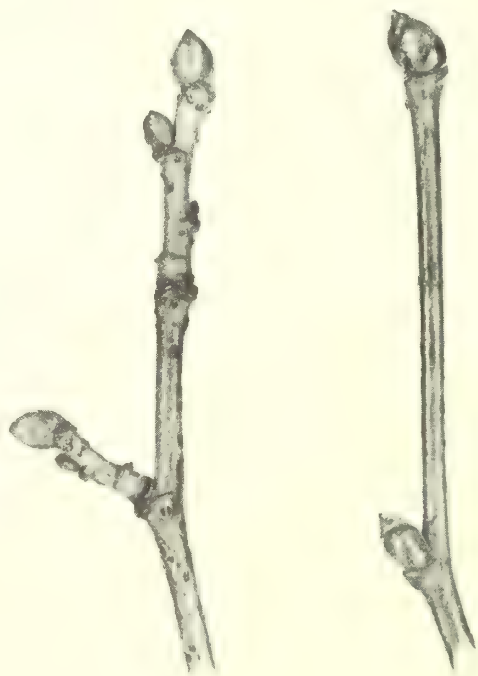
Because of its soft texture, light weight, and dimensional stability basswood lumber (including Tilia heterophylla) is a choice wood. In addition to lumber uses, it is highly desired for veneer, slack cooperage, and excelsior.

RACES AND HYBRIDS

Harrar and Harrar (8) list 16 species of basswood, all of tree size. Many of the species are small trees and some are very local in occurrence. One species, Michaux basswood (Tilia michauxii), is very similar to white basswood and some think it is a variety. Sargent (12) considers Michaux basswood to be more important than white basswood.

Little (11) tentatively accepts four species only, including white basswood, and distinguishes no varieties. He states that much field and experimental study is needed to correctly establish the species of Tilia.

Figure 2.--Typical bark, leaves and twig, and buds of white basswood.



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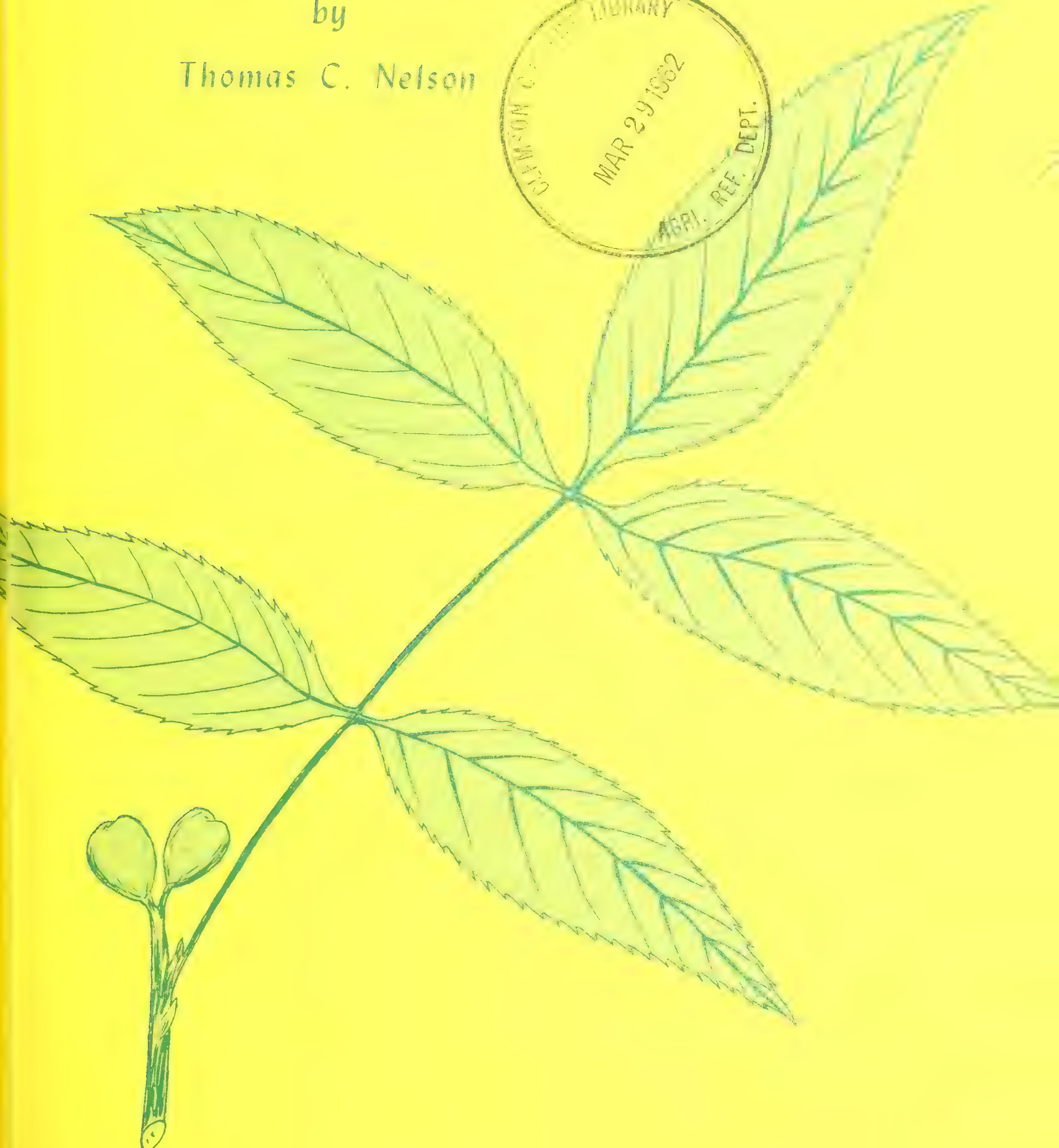
Agriculture Asheville

Silvical Characteristics of Pignut Hickory

by

Thomas C. Nelson



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U.S. Department of Agriculture
Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Pignut Hickory

(Carya glabra (Mill.) Sweet)

by

Thomas C. Nelson

"Pignut hickory," in common usage, is an ambiguous term. No less than five of the presently recognized species of hickory are called "pignut hickory" in various sections of the country. The taxonomy of the species and its varieties is still in a state of flux (10). The most widely recognized pignut hickory is Carya glabra (Mill.) Sweet and this discussion, except where specifically stated, refers to the typical variety (Carya glabra var. glabra). The binomial, Carya ovalis (Wangenh.) Sarg., was reduced to synonymy in the 1953 Check List (10), and is now included under Carya glabra var. glabra. Other common names for this variety include oval pignut hickory, red hickory, redheart hickory, small-fruited hickory, and sweet pignut. Pignut, as is true with most hickory species, loses its identity in the lumber market and is sold as "hickory" (10).

Pignut hickory is distributed from southern Maine to southern Ontario and southern Michigan south to the Atlantic and Gulf Coastal Plains (fig. 1), and reaches its largest size in the basin of the lower Ohio River (13). It is the hickory most commonly found in the Appalachian forest (12) and grows at higher elevations in the Southern Appalachians than the other hickories (13). Pignut probably furnishes most of the hickory cut in the Cumberland Mountains of Tennessee, Kentucky, and West Virginia, and in the hill country of the Ohio Valley.

HABITAT CONDITIONS

CLIMATIC

Pignut hickory grows in a humid climate and the super-humid climate (17) of western North Carolina is particularly suited for its growth and development. Average annual rainfall in its range varies from 30 inches to approximately 80 inches, 20 to 40 inches falling during the growing season. Average snowfall varies from 1 inch per year in the south to 80 inches in the north (9).

Average annual temperatures range from 45° to 65° F.; average July temperatures from 70° to 80°; and average January temperatures from 20° to 50°. Extremes of 115° and -30° have been recorded within its range. The average growing season varies by latitude from 140 to 240 days (9).

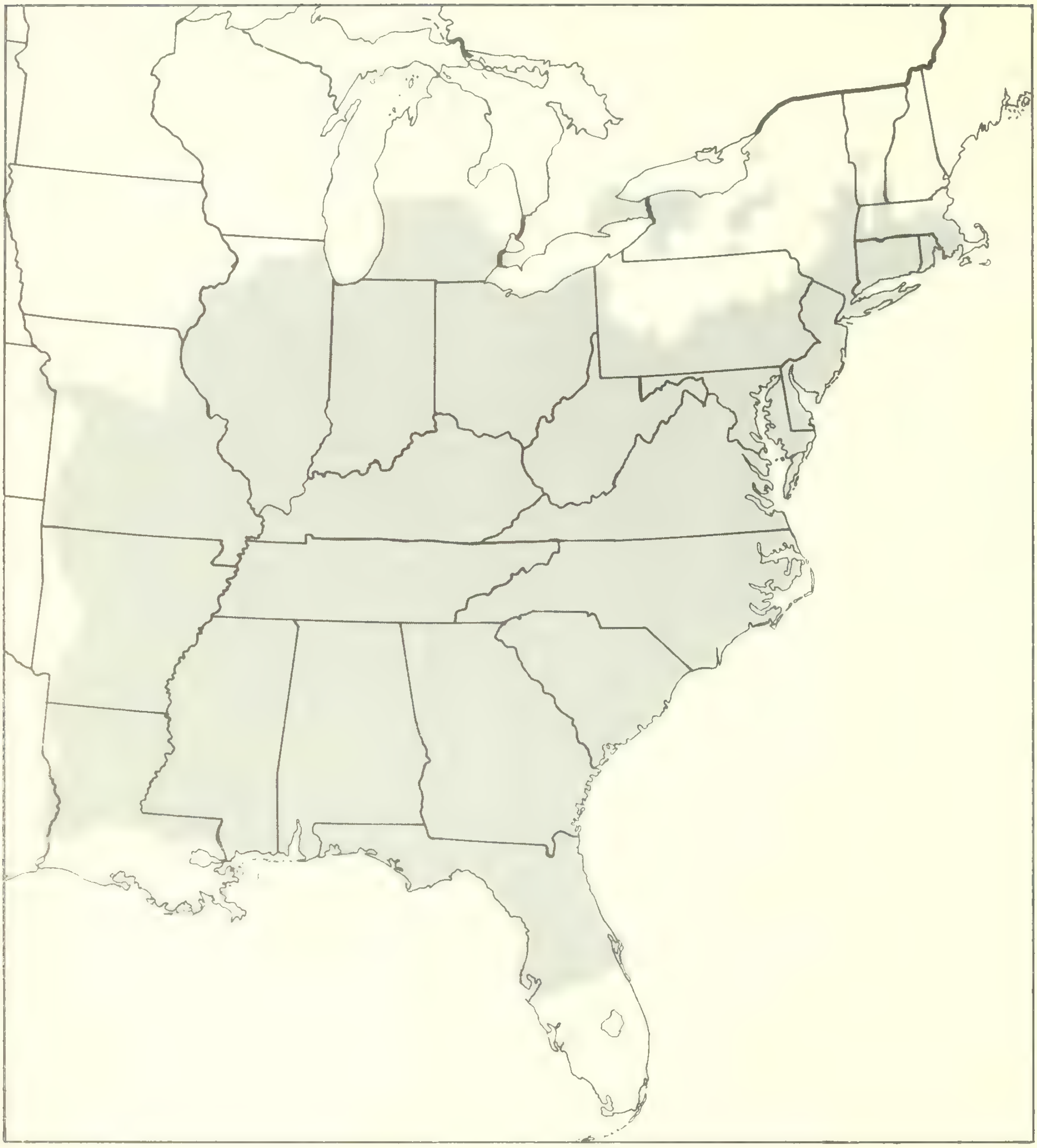

Figure 1.--Botanical range of pignut hickory.

EDAPHIC AND PHYSIOGRAPHIC

Pignut hickory, in general, inhabits dry ridges and hillsides (13) (fig. 2). According to Boisen and Newlin (5), however, it responds readily to increases in soil fertility, and Westveld (22) states that it is also common on moist sites in the Southern Appalachian region. Mitchell and Chandler (11) class pignut as intermediate in terms of tolerance or growth on nitrogen-deficient soils.

BIOTIC

Pignut hickory is usually a minor species in the types in which it is found. It is listed as a component of only two forest cover types, the post oak-black oak type and the white oak-red oak-hickory type (14). In the post oak-black oak type, it is associated with southern red oak (*Quercus falcata*), white oak (*Quercus alba*), scarlet oak (*Quercus coccinea*), shingle oak (*Quercus imbricaria*), live oak (*Quercus virginiana*), shortleaf pine (*Pinus echinata*), Virginia pine (*Pinus virginiana*), blackgum (*Nyssa sylvatica*), mockernut hickory (*Carya tomentosa*), sourwood (*Oxydendrum arboreum*), red maple (*Acer rubrum*), post oak (*Quercus stellata*), black oak (*Quercus velutina*), blackjack oak (*Quercus marilandica*) and other less important species. In the white oak-red oak-hickory type, it occurs with a number of combinations of oaks and hickories.

Braun (5), in describing the forest of the Piedmont upland, places pignut in association with loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris*), shortleaf pine, southern red oak, post oak, black oak, blackjack oak, mockernut hickory, and flowering dogwood (*Cornus florida*).

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--The flowers of pignut hickory are monoecious. The male flowers are borne in catkins from 3 to 7 inches long and are covered with a soft, scurfy pubescence. The female flowers are produced in 2 to 5 flowered spikes, about $\frac{1}{4}$-inch in length. Flowers open from the middle of March near the southwest extreme of its range to the beginning of June in New England (13).

The fruit ripens in September and October, and seeds are dispersed from September through December (20) (fig. 3).

Seed production. --Pignut hickory reaches commercial seed bearing age at 30 years, and optimum seed production occurs at ages of 75 to 200 years. The maximum age for commercial seed production is 300 years. Good seed crops occur every year or two, with small seed crops in the other years (18), and Sudworth (16) estimates that 50 to 75 percent of the fresh seed will germinate. Pignut is one of the lighter-seeded hickories, averaging 200 seed per pound (20).

Figure 2.--An open-grown pignut hickory, located in Greene County, Georgia. The tree is about 109 feet tall and 36 inches d.b.h.

Figure 3.--Typical bark, fruit, twig and bud, and leaves of pignut hickory.

The hickory shuckworm (Laspeyresia caryana) is probably a major factor in reducing germination (2).

The fruit is too small to warrant collecting for human consumption, although the kernels are usually sweet.

Seed dissemination.--The fruit of pignut is disseminated principally by gravity, but because it is attractive to animals, they are also probably important in dissemination of the seed. Some of the more important animals are red squirrel (Sciurus hudsonicus), eastern grey squirrel (Sciurus carolinensis), eastern fox squirrel (Sciurus niger), chipmunk (Tamias striatus), and raccoon (Procyon lotor).

VEGETATIVE REPRODUCTION

Although pignut hickory sprouts prolifically from the stump (4), it is generally conceded to be difficult to reproduce from cuttings.

SEEDLING DEVELOPMENT

Establishment.--Hickories, in general, require a moderately moist seedbed for seed germination (22). Pignut seems to establish itself best in a microclimate created by hardwood duff and litter.

Early growth.--Seedling growth of pignut hickory is very slow. Boisen and Newlin (4) report the following height growth of seedlings in the Ohio Valley in the open or under light shade, on red clay soil:

Age (Years)	Height (Inches)
1	3.0
2	5.8
3	8.0
4	12.0
5	17.0

Pignut is considered by Toumey to have a very inflexible rooting habit (18). The species tends to develop a pronounced taproot with few lateral roots; this is especially true of young seedlings, but it is also a strong habit in older trees--even where soil conditions are not conducive to taproot development.

SAPLING STAGE TO MATURITY

Growth and yield.--Pignut hickory often reaches 80 or 90 feet in height, and occasionally 120 feet. The trunk is frequently forked, and maximum d.b.h. is 3 to 4 feet (13). Height and diameter in relation to age for selected locations are shown in table 1.

Table 1.--Height and diameter growth of pignut hickory in selected portions of its range (4)

Age (years)	D.b.h.	Height			
	Southern Indiana, northern Kentucky 1/	Ohio Valley 1/	Northern Ohio 1/	Cumberland Mountains 2/	Mississippi Valley 2/
	Inches	Feet			
10	1.0	9	7	6	6
20	2.0	19	20	14	19
30	3.2	32	35	24	27
40	4.4	42	48	32	34
50	5.5	51	61	40	40
60	6.8	58	69	48	46
70	8.4	64	74	55	52
80	10.0	69	--	62	58
90	11.4	--	--	69	64
100	--	--	--	75	69
120	--	--	--	85	79
140	--	--	--	93	88
160	--	--	--	99	96
180	--	--	--	104	101
200	--	--	--	108	105

1/ Second growth.
2/ Virgin forest.

On both dry and moist sites of the Southern Appalachian region, pignut hickory will produce sawtimber, but in the longleaf pine-turkey oak type of the southern pine region it never reaches saw-log size (22).

Reaction to competition.--The species is classified as intolerant in the northeast and tolerant in the southeast (15). Baker (1) classifies hickories about equally as intermediate or intolerant. Pignut hickory is a climax species in the oak-hickory type throughout most of its range.

Principal enemies.--Pignut hickory is easily damaged by both frost and fire (21), which results either in degrade of the tree, loss of sound volume or both. Much degrade in Appalachian hickory is also caused by sapsucker (*Sphyrapicus varius*) injury (12).

Pignut is attacked by anthracnose (*Gnomonia caryae*) and witches' broom (*Microstroma juglandis*). A bark canker caused by *Nectria galligena* is also reported (19). Phomopsis tumor is widespread on hickories and probably occurs on pignut (6).

The most common disease of the species from Pennsylvania southward is a trunk rot caused by *Poria spiculosa*. A single trunk canker near the base is a sign that the butt log is badly affected, and multiple cankers are evidence that the entire trunk has an extensive rot cylinder (7).

An important insect enemy is the hickory bark beetle (*Scolytus quadrispinosus*); logs and dying trees are attacked by Ambrosia beetles (*Platypus compositus*) and powder-post beetles (*Xylobiops basilaris*) (2). Pignut is probably one of the preferred foods of the hickory twig girdler (*Oncideres cingulatus*), and it is attacked by several species of gall insects.

RACES AND HYBRIDS

There are undoubtedly races of pignut hickory, but its taxonomy has been subject to so many changes that differentiation of varieties, races, and separate species is confusing.

Boisen and Newlin (4) list four variants of the typical pignut; var. microcarpa, var. odorata, Hicoria villosa, and Hicoria pallida. The last two have been renamed Carya texana and Carya pallida (10).

Red or false pignut hickory was recognized until 1953 as a separate species. It is similar in its silvical habits to pignut hickory (8) and, in general, statements made for pignut hickory will be true for the red hickory variant.

Coast pignut hickory (Carya glabra var. megacarpa) is still recognized as a variety (10). It is also called Ashes hickory, hammock hickory, and southern pignut hickory. Its range extends from western New York to southern Ohio and southern Illinois, south to Louisiana and central Florida (10). In the southern portion of its range, coast pignut is limited to upland sites of the coastal plain (3).

Three distinct species in Florida have been proposed as variations of coast pignut hickory pending further field studies: Carya ashei, Carya austrina, and Carya magnifloridana (10).

One hybrid, Carya X demareei Palmer (Carya cordiformis x glabra), has been recorded (10).

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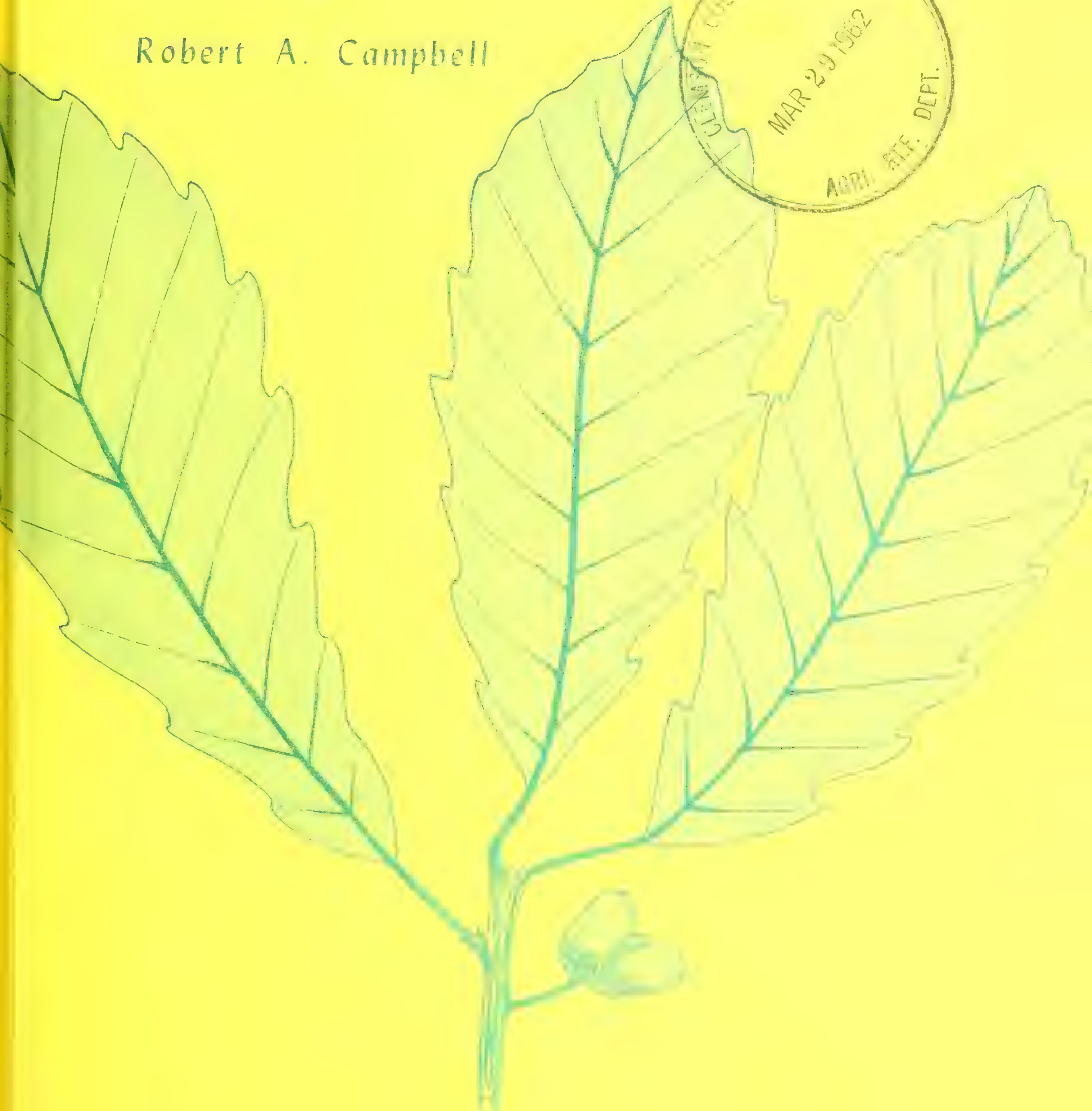
Silvical Characteristics of Chestnut Oak

by

Robert A. Campbell



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Silvical Characteristics of Chestnut Oak

(Quercus prinus L.)

by

Robert A. Campbell

Chestnut oak (Quercus prinus L.) is also called tanbark oak, rock oak, and rock chestnut oak (15). The last two names probably originated from its frequent occurrence in rocky places. The present species name is a restoration from montana, following Fernald, to the earlier name of prinus. Sudworth's check list (23) and most dendrology texts still list prinus as the species' name for swamp chestnut oak.

RANGE

Chestnut oak is of rather limited distribution compared with the other eastern oaks. In brief it is found in relatively pure stands on the slopes of the Appalachian Mountains and in the closely surrounding territory (fig. 1). Elsewhere over its range it usually occurs in small groups or individually. It reaches maximum size and quality on mountain slopes in the Carolinas and Tennessee (20).

USES

Until 1900, 85 percent of the chestnut oak cut was for its bark alone, which was used in the production of tannin. At the present time, however, it is much more valuable as a source of lumber. Betts (2) ranks it third among the oaks in volume of standing timber, and in a recent survey (17) it ranked first among all species in western North Carolina. In addition to its use as lumber, it is also extensively utilized for crossties. The lack of tyloses prohibits its use as cooperage stock.

HABITAT CONDITIONS

CLIMATIC

The climate within the natural range of chestnut oak is humid. Average annual precipitation varies from 35 to 55 inches, generally well distributed throughout the year. Seasonal temperatures vary from a low of -20° F. in the north and at the higher altitudes to a high of about 100° in the south and at the lower elevations (28).

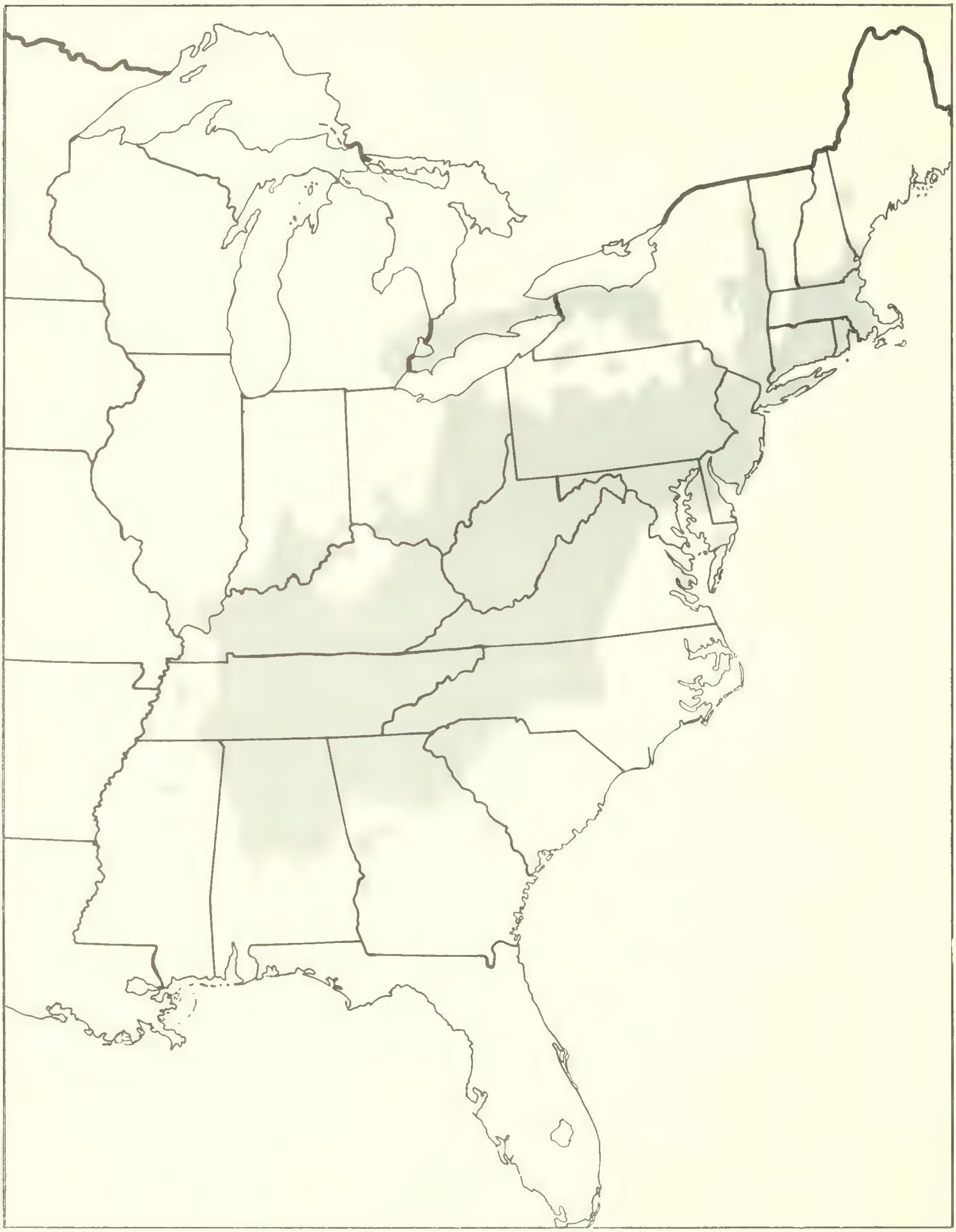


Figure 1.--Botanical range of chestnut oak.

EDAPHIC AND PHYSIOGRAPHIC

This species is found on a rather wide variety of soils within its range. It does better than most other species of oak on dry, sandy, or gravelly soils, but reaches maximum development in the rich, well-drained coves and bottoms. It grows on soils that vary from the gray-brown podzolic in the north to the red and yellow podzolic soils in the southern part of its range (25).

In the south the upper limit for the chestnut oak is at an elevation of about 4,500 feet above sea level, and its lower limit is 1,000 feet. Elsewhere over its range the species grows at elevations of less than one hundred feet. Extremes of heat and cold seem to have little effect on chestnut oak, and temperature alone is probably not a limiting factor in its distribution.

BIOTIC

Chestnut oak is a component of 11 of the 106 cover types listed for North America (22). It is a major species in two: chestnut oak (No. 44) and white pine-chestnut oak (No. 51). In the chestnut oak type it is pure or predominant, and the common associates are scarlet oak (*Quercus coccinea*), black oak (*Quercus velutina*), white oak (*Quercus alba*), pitch pine (*Pinus rigida*), blackgum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), and red maple (*Acer rubrum*).

Pure stands of chestnut oak are often found on dry rocky ridges. When chestnut oak occurs with eastern white pine (*Pinus strobus*), the associated species on the drier sites are scarlet oak, blackgum, red maple, flowering dogwood (*Cornus florida*), hickory (*Carya* sp.), pitch pine, Table-Mountain pine (*Pinus pungens*), Virginia pine (*Pinus virginiana*), post oak (*Quercus stellata*), and shortleaf pine (*Pinus echinata*). In the cove sites its associates are yellow-poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), white oak, black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), white ash (*Fraxinus americana*), and red maple.

Shrubs found with chestnut oak include the highbush blueberry (*Vaccinium corymbosum*), lowbush blueberry (*Vaccinium angustifolium*), dwarf chinquapin oak (*Quercus prinoides*), and mountain-laurel (*Kalmia latifolia*).

The chestnut oak acorn (fig. 2), because of its large size and sweet taste, is a favorite food of the white-tailed deer (*Odocoileus virginianus*) and the gray squirrel (*Sciurus carolinensis*). Because the nut is so large, only an occasional acorn is eaten by birds and then by only the larger ones, such as the turkey (*Meleagris gallopavo*) (13).

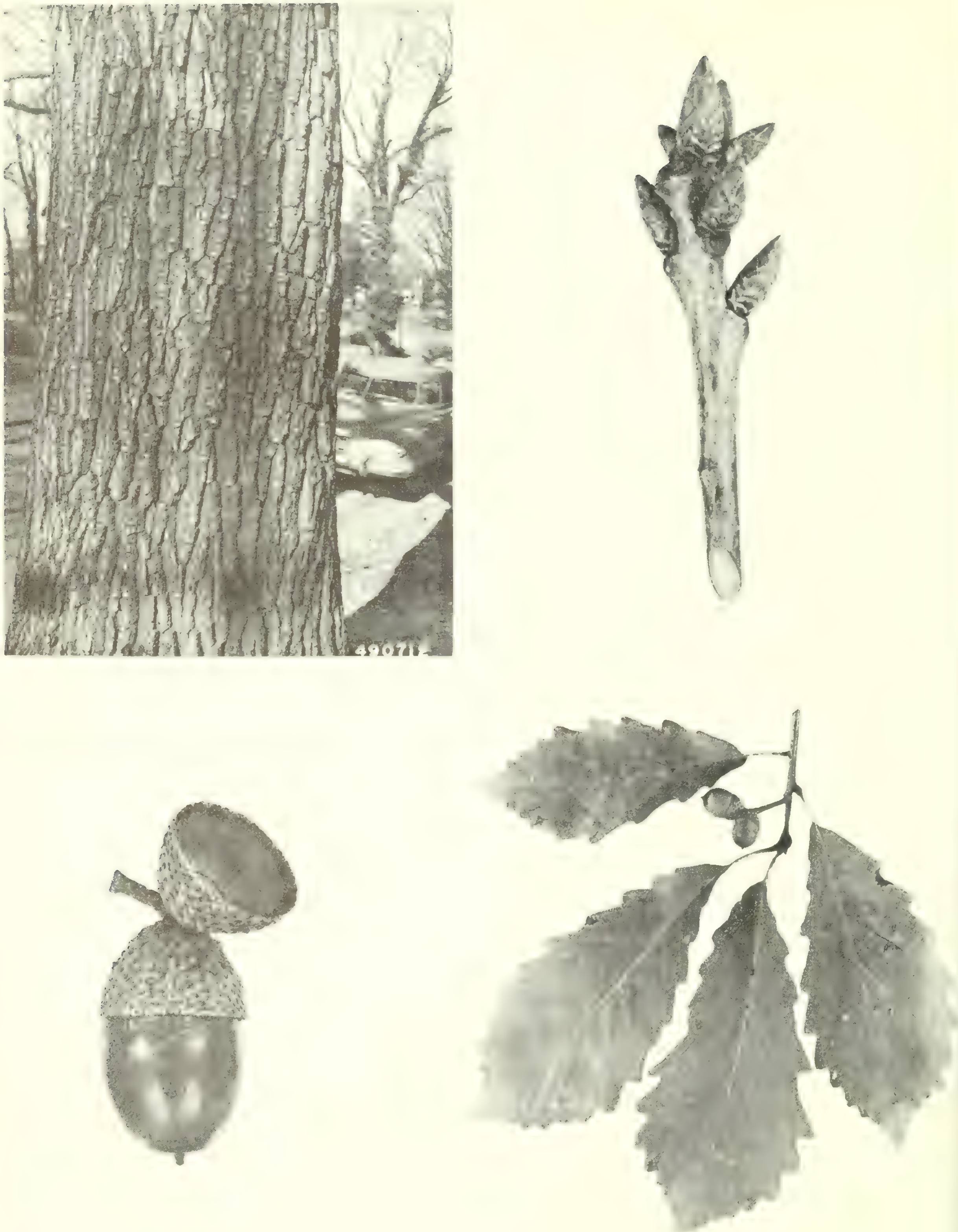


Figure 2.--Typical bark, twig and bud, fruit, and leaves of chestnut oak.

LIFE HISTORY

SEEDING HABITS

The flowering season of chestnut oak begins in early April in the Southern Appalachians and extends into May in the northern states. Wright (30) found that heavy flowering does not necessarily indicate heavy fruiting. Unfavorable weather, such as a hard freeze, may have an adverse effect.

Although chestnut oak flowers along with the other oaks, it is the first to drop its seed, according to Downs (6). There are conflicting reports on the frequency of good seed crops. One source states that good seed crops occur about once in 4 to 7 years in the Southern Appalachians (6), whereas another indicates that a good crop is produced every other year (27). A third source shows that chestnut oak is an irregular seeder, producing two good crops in 5 years (29). More studies are probably needed to determine the cycle.

Downs (6) found that acorn production increased with tree size--up to 26 inches d.b.h. In his study, well-developed acorns averaged 42 percent sound, and the percentage of sound acorns increased with larger crops.

Two authorities have reported that weevil damage in the Appalachians was more severe during years of light crops (6, 13). However, even weeviling does not necessarily preclude germination of the acorn (1). It has been found that three groups of insects are responsible for acorn damage (13): nut weevils (*Curculio* spp.), moth larvae (*Valentinia glandulella*), and gall-forming cynipids (*Cynipidae*). Moth larvae are occasionally abundant enough to do considerable damage to the acorn crop (4).

VEGETATIVE REPRODUCTION

A high proportion of chestnut oak reproduction is of sprout origin, and it is estimated that 75 percent of the chestnut oak reproduction in the Southern Appalachians originated from sprouts (7). Frothingham (8) states: "Among the oaks, chestnut oak is the most prolific and persistent sprouter." In common with associated oaks, sprouting is very successful when stumps are small, but decreasingly so as the size and age of the stump increases (16).

According to Roth and Sleeth (19), decay of chestnut oak sprouts in the larger stump sizes is serious. Even so, they found that chestnut oak had the lowest percentage (11 percent) of decayed sprouts of all oak species. Once decay has been transmitted from the stump to the sprout, rot may weaken the tree to a point where it falls easy prey to a high wind.

SEEDLING DEVELOPMENT

Chestnut oak seeds germinate soon after falling if conditions are favorable (fig. 3). In the Central States, Barrett found that litter depth is the most important single factor positively correlated with germination and early sur-

Figure 3.--Two-month old chestnut oak seedling; stem approximately 4 inches long.

vival (1). A minimum litter depth of 1 inch and a maximum of 2 inches appeared best for both germination and early survival. It was also found that shade had a slightly favorable effect on germination. Fall seeding without stratification is the recommended nursery practice (27).

Because oaks probably represent the climax vegetation stage, they are capable of growing in all-age stands. Downs (6) reported that partial cutting in the Southern Appalachians provides more favorable conditions for germination than seed-tree cutting. He recommends a 2-cut shelterwood method, with the first cut providing for germination and the second for growth.

Kuenzel and McGuire (14) clearly indicated that a reduction of 50 percent of the original basal area failed to provide as good survival or growth conditions as clear cutting following establishment of a good crop of seedlings in the Central States. Total height growth of seedlings 10 years after establishment averaged 0.5 foot on the uncut area, 0.8 foot on the released area, and 4.8 feet on a clear-cut area. Sprout growth on the clear-cut area was even better, averaging over 21 feet.

Squirrels, chipmunks (Tamias striatus), and mice (Peromyscus sp.) are commonly regarded as the most important consumers of acorns, but in a study at the Bent Creek Experimental Forest, near Asheville, N. C., deer were regarded as more important than rodents (6). In the past, frequent and severe ground fires in the late fall and early spring have reduced the stocking of oak seedlings and sprouts which otherwise might have produced adequate stands.

Chestnut oak is a medium-size tree normally maturing at 60 to 80 feet in height and 20 to 30 inches d.b.h., depending on site (2). Maximum size is 100 feet tall and up to 6 feet in diameter (10).

As with most of the white oak group, growth is slow (fig. 4). Furthermore, because the species so often grows on poor sites, physiological maturity comes at a relatively late age. Trimble's West Virginia study (24) showed that chestnut oak has a site index ratio of 0.98, compared with northern red oak at 1.00, and white oak at 0.95 on the same site. In all vigor classes, Campbell (5) found chestnut oak growing faster in the Southern Appalachians than American beech (Fagus grandifolia), the hickories, or yellow birch (Betula alleghaniensis), but slower than the red oaks, American ash, red maple, or sugar maple (Acer saccharum). McIntyre's study (18) of oak radial growth rates in Pennsylvania proved that chestnut oak was the slowest growing of the five oaks studied. Perhaps the discrepancy between the West Virginia and the Pennsylvania growth findings could be explained by the fact that the West Virginia study is based on height growth, whereas the Pennsylvania study is based on radial growth.

Chestnut oak responds well to thinning; this is especially true of sprout clumps of the U-type, which should usually be thinned to a single sprout.

Sawtimber yields of pure chestnut oak stands on the better dry slopes and ridges of the Southern Appalachians amount to 7,000 board feet at 80 years of age, according to Frothingham (8). He also estimated annual growth at 90 board feet per acre during the 10-year period between stand age 70 and 80 years. Maximum periodic growth for the typical chestnut oak site is reached at about 100 years of age and is estimated at 100 board feet per acre per year (8). Yields in cords for the same site and age are estimated at 38 cords total and a periodic growth rate of $\frac{1}{2}$ cord per acre per year.

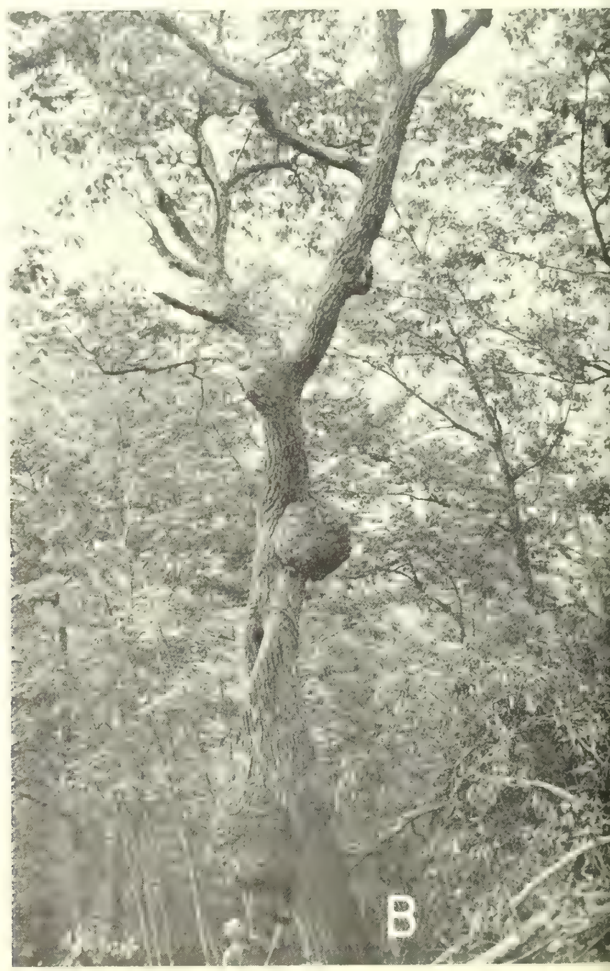
Chestnut oak in the mountain region of western North Carolina contributes one-eighth of the total volume of all sawtimber--more than any other single species (17). It is believed that this same proportion would hold true for many other areas of the Southern Appalachians.

Economic maturity, based on lumber values and average growth rates, on average to good sites ranges from 21 to 25 inches d.b.h. (5). The larger diameter applies to trees found on the better sites and those with good vigor. On poor sites it is doubtful if the trees will ever reach these sizes.

Principal Enemies

One of the few species that will grow on dry sites and ridges where burning is frequent and sometimes intense, chestnut oak suffers considerable fire damage. If fire doesn't kill the tree outright, it slows the growth and usually results in butt rot. This in turn results in both volume and quality losses.

Figure 4.--A, forest-grown mature chestnut oak, Buncombe County, N. C. This tree is 29 inches d.b.h., 87 feet tall, and nearly 250 years old. B, Defective chestnut oaks of low quality are not uncommon, especially on poor sites.



Chestnut oak is subject to oak wilt (Ceratocystis fagacearum) but, being a white oak, it is less susceptible than most of the red oak group (26). It is also susceptible to a conspicuous twig blight caused by Dipladia longisporia. Boyce (3) lists the common oak decay fungi as the sulphur fungus (Polyporus sulphureus), (Polyporus spraguei), hedgehog fungus (Hydnum erinaceus) and string rot (Armillaria mellea). Strumella coryneoidea and Nectria sp. are serious oak cankers in some localities, especially from Virginia northward (11). Chestnut oak is one of the oaks most resistant to typical heart and sapwood decays (21). Nevertheless, in old and frequently burned stands it is usually a very defective tree.

Chestnut oak is relatively resistant to most insect borer attacks, but the species is quite susceptible to the pin or shot hole type of beetle. In eastern Kentucky, chestnut oak logs were found least infested with borers of all oaks studied (9); however, because of heavy damage by shot hole insects, the total volume loss of chestnut oak from both shot and bore holes was greater than for any other oaks--amounting to 46 percent.

Among the most destructive pin or shot hole insects in chestnut oak are the ambrosia beetles, of which the Columbian timber beetle (Corthylus columbianus) is well known for boring in otherwise sound wood. Members of two other ambrosia beetle genera (Platypus and Xyleborus) are also important, but usually they are not serious until the trees are weakened by fire or drought (12). The oak timberworm (Arrhenodes minuta), though not an ambrosia beetle, is a common insect that enters the tree through wounds and produces tiny pin holes in the wood sometimes rendering the tree useless (12).

Two very important borers in chestnut oak are the carpenter worms (Prionoxystus robiniae and Prionoxystus macmurtrei) which tunnel in all directions in both the heartwood and sapwood of trees. The holes, often as large in diameter as one's finger, may extend for several feet.

Among the important defoliators are the spring and fall cankerworm (Paleacrita vernata and Alsophila pometaria) and the forest tent caterpillar (Malacosoma disstria). June beetles (Phyllophaga spp.) are sometimes important defoliators along with species of Datana. The gypsy moth (Porthetria dispar) is an important oak defoliator in parts of the northeast.

Gall insects and the pit-making oak scale often cause the death of branches and occasionally may cause the death of entire trees.

SPECIAL FEATURES

The bark of chestnut oak contains about 12 percent tannin (10), and the production of sole leather tannin from the bark was an important use until 1950, even for low grade trees. Synthetic sole leather substitutes have now largely taken over.

RACES AND HYBRIDS

No races of chestnut oak are known. Sargent (20) reports chestnut oak crossing with *Quercus robur* to form the hybrid *Quercus x sargentii* Rehd., but Little (15) says this cross occurs only under cultivation. Little also reports the following crosses: *Quercus x bernardiensis* (*Quercus prinus x stellata*) and *Quercus x saulii* (*Quercus alba x prinus*) (fig. 5).

Figure 5.--Natural hybrid of chestnut oak, *Quercus alba X prinus* to form *Q. X saulii*. Tree located near Carnesville, Georgia.

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Silvical Characteristics of Southern Magnolia

(*Magnolia grandiflora* L.)

by

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Southern magnolia is the largest species of its genus (2). Its range extends from southeastern North Carolina along the Atlantic coast to the Peace River in De Soto County, Florida, and westward along the Gulf coast to the valley of the Brazos River in southeastern Texas (9, 15, 19). It reaches inland for about 100 miles, except in the Mississippi delta, where it grows throughout the State of Louisiana and into southern Arkansas and central Mississippi (fig. 1). In the South it is widely planted as an ornamental. Plantings have also been made as far north as St. Louis, Missouri; Collinsville, Illinois; Washington, D. C.; New Jersey; and Massachusetts. It is reported as being precariously hardy in these regions (4, 12). Plantings along the Pacific coast as far north as British Columbia have been reported (2).

Within its range southern magnolia is commonly referred to as bull bay, evergreen magnolia, or flowering magnolia.

HABITAT CONDITIONS

CLIMATIC

The climate in which southern magnolia grows can be described as warm-temperate to semitropical. Temperatures in general are mild and the growing season long. In a major portion of the range the frost-free season is more than 240 days (14). In the more temperate areas of its range the growing season is from 210 to 239 days. Along the coast, average January temperatures range from 51° to 54° F. in South Carolina and Georgia, and up to 56° in Louisiana (6, v. 10, 14, 20). Mean January temperatures in Florida range from 60° to 70°. July averages for the coastal areas range from 79° to 83°. Inland temperatures within the range of the species may vary from 3° to 5° from these averages. Temperatures below 15° or above 100° are rare within the range of southern magnolia.

Annual rainfall averages 40 to 50 inches in the northeastern portion of its range and 50 to 60 inches in other areas. A small area along the Gulf coast receives 60 to 80 inches yearly. Normally, rainfall is well distributed throughout the year within the range of southern magnolia.

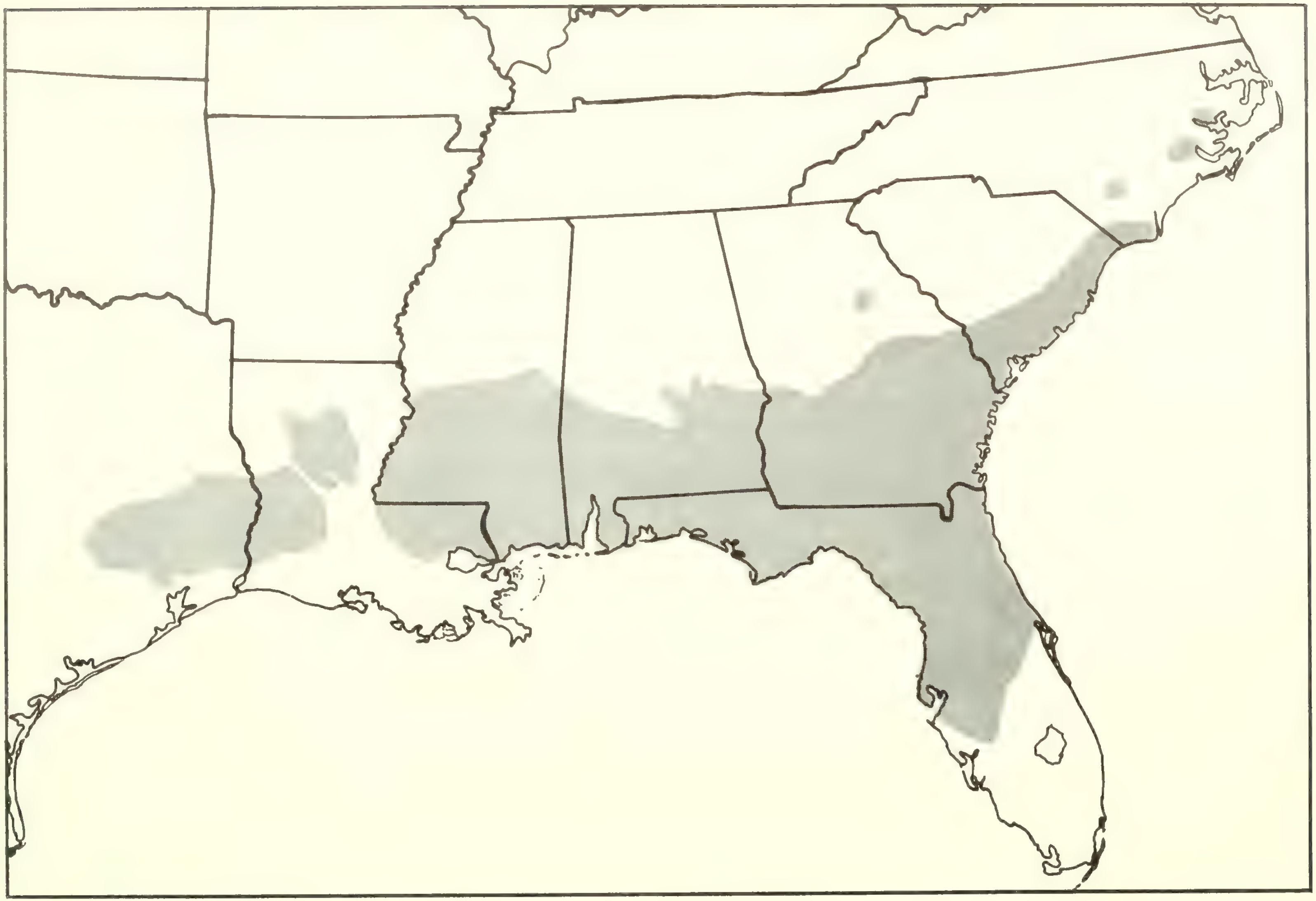

Figure 1.--Botanical range of southern magnolia.

EDAPHIC

Southern magnolia makes its best growth in damp, well-drained soils that are rich in humus and situated along streams or near swamps in the coastal plain area, and in low, moist sites in the upland areas (2, 3). However, numerous ornamental plantings throughout the South indicate the species will grow and thrive on a variety of soils. Although by nature a bottomland species, it cannot withstand prolonged inundation and does not occur on bottoms subject to constant or regular overflow. It does not occur on the lower bottoms of the Mississippi that were regularly overflowed before the levees were built, and it occurs only occasionally on the higher bottoms (1, 2).

Along the coast, the sites on which southern magnolia occurs belong to the Wiesenboden, ground water podzol, and half bog soils of the intrazonal group (18). The primary soils in this area are the Leon-Bladen, Coxville-Portsmouth-Bladen, and Lake Charles-Crowley associations. Farther away from the coast, as in central Florida, Georgia, and in the states to the west, the soils in the natural range of the species belong to the red and yellow podzolic soils of the zonal group. The Norfolk-Ruston association covers the major portion of this area. The Norfolk-Blanton, Greenville-Magnolia, Memphis-Grenada, and Caddo-Beauregard associations are also represented.

PHYSIOGRAPHIC

No portion of the natural range of southern magnolia is over 500 feet in elevation (14). In fact, a great part of the area is less than 200 feet above sea level. The average elevation for the entire State of Louisiana is only 100 feet, and that of Florida is little greater (6, v. 9, 14). The coastal areas of other states within the range of the species are all at 100 feet or less. The northern extreme of its range in Georgia, Mississippi, and Arkansas approaches altitudes of 300 to 400 feet.

The latitudinal range of southern magnolia is from approximately 27°N. to about 35° N.

BIOTIC

Southern magnolia does not grow in pure stands (1, 2). Usually it is associated with blackgum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*), the lowland oaks, and other lowland species. It is listed as a chief associate in only the live oak forest type--a climax type--by the Society of American Foresters (16). Putnam (13) lists the species as a component of his white oaks-red oaks-other hardwoods type which combines the hickory-swamp chestnut oak-white oak, redgum-swamp red oak, and oak-elm-ash types as set forth by the Society of American Foresters.

This combination also embraces limited areas of pine-hardwood types, which include loblolly pine (Pinus taeda) and spruce pine (Pinus glabra). Eggler (7) suggests that southern magnolia, along with live oak (Quercus virginiana) and water oak (Quercus nigra), is generally a member of the climax forest in southern Louisiana.

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--The large, fragrant flowers of southern magnolia are formed from April to June within its natural range (fig. 2). Plantings farther north may flower as late as August (4, 15). The flowers are creamy white, 6 to 8 inches across, have from 6 to 12 petals, and are very delicate. The petals all have a spot of color at the base, which gives the flower a purple center. Each flower lasts from two to several days, according to the weather.

At the falling of the petals, the oval fruit appears. In the juvenile stage, it is pink and covered with thick, lustrous hair. At maturity, both fruit and hair are a rusty brown. Measuring 3 to 4 inches in length and $1\frac{1}{2}$ to 2 inches in thickness, the follicle-type fruit matures from September to late fall. The seed are red, oily, kidney-shaped, about one-half inch long, have a pleasant cinnamon-like odor, and when the cone opens, hang for a while by slender, silken threads before dropping to the ground.

Seed production.--Southern magnolia is generally a prolific seed producer, being essentially the most floriferous forest tree. According to Kyle (11), each new shoot on every limb bears a flower, and in turn a fruit with numerous seed. Pring (12) reported one specimen produced abundant seed about 10 years after being planted in the St. Louis area. It was 5 feet high when planted. He mentions other planted specimens that produced numerous seed at early ages when they were 8 to 9 inches in diameter.

Seed dissemination.--Ordinarily the fruit is ripe by September--at least in the southern areas--the follicles open, and the seed begin to fall. Natural dissemination is accomplished mostly by birds and animals, the seed being too heavy to be distributed by air currents. Examinations show the seed are a part of the diet of squirrels (Sciurus sp.), opossums (Didelphis virginiana virginiana), quail (Colinus virginianus), turkey (Meleagris gallopavo), and other rodents and birds. The washing action of heavy rains and flash floods may cause some movement of seed.

Figure 2.--Typical bark, fruit and leaves, twig and bud of southern magnolia.

SEEDLING DEVELOPMENT

Establishment.--Evans (8) reports that the seed of southern magnolia, although viable, rarely germinate when shed from the tree. Kurz and Wagner (10) later supported this with the report that the species does not reproduce within the area dominated by the canopy and root system of the parent tree. Evans demonstrated further that neither the seed nor the seedling can withstand a light freeze for 48 hours. This accounts for the limited natural range of the tree.

The dormancy of southern magnolia seed is thought to be associated, in part at least, with the lignified seed coat. It is believed that the hard endosperm requires an unusual length of time for the absorption of sufficient water for germination. Tests have further shown that seeds set to germinate with the fleshy outer coat retained are destroyed by fungi (8).

Nurserymen report that if the seed are allowed to dry out they will lie over for a year before sprouting, if they sprout at all. They advise macerating the seed and stratifying them in moist sand until planting time in the spring.

According to Pring (12), young plants in the nursery average 18 to 24 inches in height growth yearly.

Early growth.--Little is known about the early growth and development of southern magnolia, especially in its natural state. A few reports are available on specimens planted in the St. Louis area. Twelve trees grown from seed collected locally were planted in the Missouri Botanical Garden in 1940. All grew well and in 1946 were 5 feet or more in height. At this time two were transplanted, and one of them more than doubled its height in the succeeding 4 years. Another specimen, about 5 feet in height, was obtained from a Georgia nursery in 1934. In 1950 it was reported as being 20 feet in height and about 10 inches in diameter. Similar growth for other plantings in the same area is reported. Under favorable conditions in its natural state it is classed as making fairly rapid growth (1, 2).

SAPLING STAGE TO MATURITY

Growth and yield.--Southern magnolia will endure a considerable amount of shading in its early life but requires more sunlight as it grows older. Under favorable conditions, forest-grown trees generally reach a height of 60 to 80 feet at an age of 80 to 120 years, and are not uncommonly 2 to 3 feet in diameter (1, 2, 9). Occasional trees exceed 100 feet in height and approach 5 feet in diameter. In 1917, Kyle (11) reported heights of 100 to 125 feet in Florida, with the largest known tree measuring 18 feet in circumference at the base. Sawtimber-size trees are frequently clear of limbs for 40 feet above ground (fig. 3).

Figure 3.--Forest-grown southern magnolia from middle coastal plain of Georgia, near Cordele. Note the clear bole of high-quality saw logs.

Since southern magnolia does not occur in pure stands, estimates of yields are not available. The most recent forest survey, which covered the entire range of the species, did not find southern magnolia in sufficient quantity in any state to warrant listing it as a separate species. Estimates, however, place the existing stand at not less than 1 billion board feet.

Southern magnolia is relatively free of insect pests (17, pp. 61, 78). Although no serious attacks have been reported in forest stands, several scale insects such as the magnolia scale (*Neolecanium cornuparvum*), oleander scale (*Asterolecanium pustulans*), and tulip tree scale (*Toumeyella liriodendri*) may attack the tree and can cause injury (5).

Although a number of fungi, including species of *Cladosporium*, *Collectotrichum*, *Glomerella*, *Phyllosticta*, and *Septoria* cause leaf spots on southern magnolia, none appear to be damaging to forest stands. *Fomes geotropus* causes a heart rot of the species.

SPECIAL FEATURES

The seed of southern magnolia were once used in making a rare perfume which possessed the same delicate scent as the flower (11).

A study of fossils indicates that the magnolias are among the most ancient trees of the world (2). The size and simple construction of the flower further indicate this. The present magnolias are thought to be a remnant of a very extensive group of north temperate forest trees which grew in Europe, Siberia, North America, and Greenland before the Glacial Period. Their history is believed to be about as ancient as that of the ginkgo, and the ranges of the two are thought to have been similar in early times.

The foliage is commonly used for decorative purposes, especially at Christmastime. Because of its stability under a wide variety of temperature and humidity conditions, the wood of southern magnolia has been widely used in the past for the manufacture of venetian blinds, and at present it is being used in the furniture industry.

RACES AND HYBRIDS

To date evidence of the existence of racial strains or hybrids in southern magnolia has not been established.

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Value Growth of Pine Pulpwood on the George Walton Experimental Forest

by

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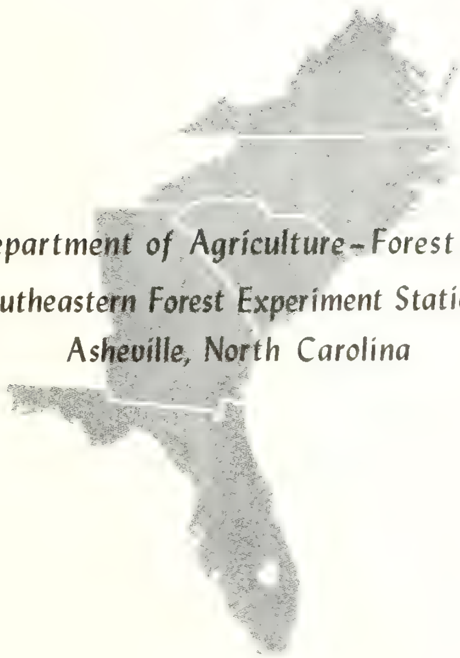

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Value Growth of Pine Pulpwood on the George Walton Experimental Forest [1]

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INTRODUCTION

In order to maximize profit it is necessary that the grower of pine pulpwood not only retain the proper amount of growing stock but also select the proper trees to remove when thinning. Those trees not expected to earn their way over the next growth period should be harvested. To a considerable extent, therefore, profit maximization depends on the actions of the timber marker.

The financial maturity concept provides a method for selecting trees to retain as growing stock so as to maximize profits from timber growing. To apply this concept to timber marking decisions, it is necessary to determine and compare two factors, the alternative rate of return of the owner and the value growth rate of the timber. The alternative rate of return is the minimum rate, expressed in compound interest form, that the owner will accept on investments of equal risk.[2] This rate will vary considerably, depending on the individual owner's economic situation.

Value growth is the increase in value obtained by retaining a tree over an additional growth period. It is generally expressed as a compound interest rate based on the value of a combination of quantity and quality growth of growing stock for a given period of time. Financial maturity is reached when the tree's value growth rate expected over the future period is equal to the owner's alternative rate of return. Marking guides based on financial maturity are in demand because of the growing realization among forest owners that adequate profit must be forthcoming to justify increases in growing stock.

1/ This paper is based on research reported in a thesis submitted to the School of Forestry of Duke University in partial fulfillment of the requirements for the degree of Master of Forestry.

The George Walton Experimental Forest, located near Cordele, Georgia, is maintained by the Southeastern Forest Experiment Station in cooperation with Mr. Holt E. Walton.

2/ A discussion of the alternative rate of return and its determination may be found in: "Financial Maturity: A Guide to Profitable Timber Growing" by William A. Duerr, John Fedkiw, and Sam Guttenberg. U. S. Dept. Agr. Tech. Bul. 1146, 74 pp. 1956.

Of the two factors defining financial maturity, the value growth rate is the only one that can be quantified objectively and thus is susceptible to research. The other determinant, the alternative rate of return, cannot be fixed by anyone but the owner.

The first objective of the study described in this paper was to isolate recognizable tree characteristics that are useful indicators of the future value growth rate. A second objective was to demonstrate the application of financial maturity concepts to longleaf and slash pine pulpwood management.

THE STUDY AREA AND SCOPE

A study of pine pulpwood value growth was carried out in the summer of 1958 on the George Walton Experimental Forest in the middle coastal plain of Georgia. Much of the area was previously agricultural land, having been mostly cropped for cotton and peanuts. The topography is level to gently rolling, and soils are predominantly loamy sands with a sandy clay subsoil. Summers are hot and humid and the growing season quite long.

Pine stands under study were managed in even-aged groups. Past management was effected through a series of improvement cuts, each operation removing the poorest individuals. Stand health and vigor was improved by each of these cuts. It became increasingly necessary, however, to choose between trees of apparent equal silvicultural worth in timber marking operations. The point was reached, therefore, where financial guides to timber marking were needed.

Naturally regenerated pulpwood-sized stands of longleaf and slash pine were studied. Pulpwood value growth was studied from the viewpoint of a stumpage seller in order to develop marking rules useful in guiding thinning operations. No measure of quality growth was included because no price differential is paid for pulpwood quality. Two additional assumptions were made: (1) no change in pulpwood prices would occur during the growth period, and (2) a uniform price would be paid for all tracts, regardless of differences in logging costs. Under these conditions, value growth rate is identical to volume growth rate.[3]

Since the study was limited to the George Walton Experimental Forest, the results are directly applicable only to this area. They are useful, however, for comparative purposes throughout the longleaf-slash pine type in the middle coastal plain of Georgia.

3/ Most management costs are expended on a per-acre basis and will influence the length of rotation of the final crop trees. Such costs do not, however, enter into marking decisions in a thinning operation.

STUDY METHODS

The 5-year interval, 1953-57, was selected as the measured growth period. As a first step in development of value growth percents (value growth rate expressed as percent of capital value), volume growth rates were established for both species.

Study plots were purposively selected to sample the available range of ages, sites, and densities. Sampling was accomplished on temporary, circular one-fourth acre plots, with uniform stand and site conditions established after the stands had been selectively marked for cutting.

The study data were of two types: stand measurements, and individual sample tree measurements. Stand variables measured included stand density in 1953 (established by stand reconstruction techniques) and site index (50-year basis).

Sample trees were those marked for removal in a commercial pulpwood operation. The sample trees were all vigorous, comparable in age and size to trees retained in the stand, and in a round condition (i.e., had not been chipped for naval stores). Trees with a 1958 d.b.h. below 4.6 inches or a merchantable height of less than one 5-foot bolt were not sampled. Badly deformed or diseased trees and trees infested by insects or damaged by fire or lightning were not sampled, nor were isolated (wolf) or severely suppressed trees.

Sample tree data included past age, past merchantable height to both the 2-inch and 3-inch top limit d.i.b., and past diameter at breast height.[4] Crown class and crown ratio of each sample tree were noted. Past crown ratio was estimated by relating 1958 crown ratio to tree characteristics by multiple regression techniques, and inserting past known values of these tree characteristics into the regression equations to predict past crown ratios. Consistent with known patterns of development in southern pine, crown class was assumed to have remained the same over the 5-year growth period.

Taper measurements and increment borings were taken over the bole length of the felled sample trees. Volume growth was then calculated as the difference between past and present planimetered merchantable volume diagrams. Top diameter limits were the only merchantability restrictions imposed on trees in the analysis.

A total of 225 sample trees was measured on 34 plots. Of these sample trees, 146 were longleaf pine and 79 were slash pine. The number of sample trees measured per plot varied from 2 to 14, averaging 6.6.

4/ "Past" in this paper refers to the value of the characteristic at the beginning of the 5-year growth period (1953).

CUBIC-FOOT VOLUME GROWTH

Longleaf Pine

Analysis of the longleaf pine cubic-foot growth data yielded the following equations:[5/] [6/]

Top diameter 2.0 inches inside bark

$$G = -0.915365 + 0.005806\ [(D.b.h.)(CR)] + 0.000248\ [(SI)(CR)] + 0.303048\ [(D+C)-(I+S)]$$

The independent variables accounted for 78 percent of the variation around the mean and the standard error of estimate was 0.471 cubic foot.

Top diameter 3.0 inches inside bark

$$G = -0.868449 + 0.005744\ [(D.b.h.)(CR)] + 0.000247\ [(SI)(CR)] + 0.300461\ [(D+C)-(I+S)]$$

The independent variables accounted for 76 percent of the variation around the mean and the standard error of estimate was 0.494 cubic foot.

5/ Data were fitted to the form:

$$G = b_0 + b_1\,(BA) + b_2\,(SI) + b_3\,(1/N) + b_4\,(A) + b_5\,[(BA)(A)] + b_6\,[(SI)(A)] + b_7\,(H) + b_8\,(CR) + b_9\,(D.b.h.) + b_{10}\,[(D.b.h.)(CR)] + b_{11}\,[(SI)(CR)] + b_{12}\,[(D+C)-(I+S)] + b_{13}\,[(D+I)-(C+S)] + b_{14}\,[(D+S)-(C+I)]$$

where

G = five-year merchantable volume growth (excluding bark), cubic feet
BA = stand basal area at the beginning of the growth period, square feet per acre
SI = site index (50-year basis), feet
N = number of trees (1-inch d. b. h. and over) per acre at the beginning of the growth period
A = age at the beginning of the growth period, years
H = merchantable height to 2-inch and 3-inch tops (inside bark) at the beginning of the growth period, feet
CR = crown ratio at the beginning of the growth period, percentage of total height in live crown
D. b. h. = diameter at breast height at the beginning of the growth period (outside bark), inches
D = dominant crown class
C = codominant crown class
I = intermediate crown class
S = suppressed crown class
$b_0, b_1 \ldots b_{14}$ = partial regression coefficients

6/ Values of the crown class comparison variables were derived for each tree by simply inserting a value of unity for the appropriate crown class, inserting zeros for remaining crown classes, and summing the expression.

Slash Pine

The slash pine cubic-foot growth data yielded the following equations:[7/]

Top diameter 2.0 inches inside bark

$$G = 0.408181 + 0.007282\,[(\text{D.b.h.})(\text{CR})] - 0.212243\,(\text{Av. Stand D.b.h.}) + 0.180083\,[(D+C)-(I+S)] + 0.186319\,(\text{D.b.h.})$$

The independent variables included in this equation accounted for 71 percent of the variation around the mean. The standard error of estimate was 0.482 cubic foot.

Top diameter 3.0 inches inside bark

$$G = 0.326468 + 0.007621\,[(\text{D.b.h.})(\text{CR})] - 0.220384\,(\text{Av. Stand D.b.h.}) + 0.190537\,[(D+C)-(I+S)] + 0.211590\,(\text{D.b.h.})$$

The independent variables in the above equation accounted for 71 percent of the variation around the mean. The standard error of estimate was 0.506 cubic foot.

The range of data used to develop the above equations is presented in table 1.

Changes in growth rate attributable to the crown class variables indicate that as far as future merchantable cubic-foot volume growth is concerned it is quite important to recognize whether a tree is in the upper two or lower two crown classes. There was not, however, any significant difference found between the growth of dominant and codominant trees, or between intermediate and suppressed trees.

Table 1.--Range of 1953 data used in volume growth equations

Species	Basal area	Site index	Trees per acre	Age	Merchantable height to 2-inch top limit	Merchantable height to 3-inch top limit	Crown ratio	D.b.h.	Average d.b.h. of stand
	Sq. ft. per acre	Feet	Number	Years	Feet	Feet	Percent	Inches	Inches
Longleaf pine	9 to 124	53 to 101	92 to 1148	10 to 41	6 to 55	0 to 48	38 to 76	2.8 to 9.5	3.2 to 11.8
Slash pine	16 to 124	59 to 103	128 to 1148	7 to 32	2 to 62	0 to 58	26 to 57	2.0 to 10.8	2.3 to 10.9

7/ Two of the variables found to be significant in the slash pine analyses, 1/N and BA, were combined into a single variable, Average Stand D.b.h., and the analyses recomputed to shorten and simplify the resulting equations.

The equations indicate that merchantable cubic-foot volume growth increases as diameter at breast height, crown ratio, and crown class increase. For longleaf pine, growth also increases with increasing site indices. For slash pine, growth decreases as average stand diameter increases. These findings agree with what would be expected on the basis of present silvicultural knowledge.

The absence of site index as a significant variable in the slash pine equations is difficult to explain. Perhaps less variation in site quality in this species than in the longleaf pine sample is an explanation. Another consideration is that site index curves are not as dependable for younger age classes as for older ones. Slash pine site indices were based on an average age of 24.6 years, compared to 38.5 years for longleaf pine. Age likely did not occur as a variable in either set of equations because variation in age was small within species and age is correlated with diameter when density, site, and crown class are accounted for.

The longleaf pine sample adequately represented the range of ages, sizes, sites, and densities encountered in the study area, but the slash pine sample did not. The slash pine trees sampled were concentrated in the smaller size and younger age classes. It was desirable, of course, to sample trees which had not yet become merchantable for pulpwood at the beginning of the growth period in order to discover growth trends in the lower diameter and younger age classes.

The concentration of the slash pine data in the smaller size and younger age classes resulted mainly because the sampled classes were the only ones available during the period field work was in process. Also, it was difficult to secure adequate distribution of sample trees with regard to many of the variables employed in the growth function because the applicable values of the variables had to be derived employing stand and tree reconstruction techniques.

PULPWOOD VALUE GROWTH PERCENTS

Tables showing the value growth percents were constructed from merchantable volume growth equations (tables 2 to 9).

In order to convert volume growth to value growth percent it was necessary to solve the following formula for p:

$$(1+p)^n = \frac{Vn}{Vo}$$

where

p = value growth rate, percent
Vn = volume at the end of growth period, cubic feet
Vo = volume at the beginning of growth period, cubic feet
n = growth period, years.

Table 2.--Expected value growth percents for longleaf pine pulpwood over a 5-year period for dominant and codominant crown classes with a top diameter of 2.0 inches inside bark

D. b. h. (inches)	Crown ratio - percent				
	30	40	50	60	70
			Percent		
SITE INDEX 60					
4	8.7	13.5	17.7	21.3	24.6
5	5.6	8.5	11.2	13.7	15.9
6	4.3	6.4	8.4	10.3	12.0
7	3.5	5.3	6.8	8.3	9.8
8	3.1	4.4	5.8	7.0	8.2
9	2.7	3.9	5.0	6.1	7.2
SITE INDEX 70					
4	9.7	14.7	18.9	22.6	25.9
5	6.1	9.2	11.9	14.4	16.7
6	4.6	6.8	8.9	10.8	12.6
7	3.8	5.5	7.2	8.7	10.2
8	3.2	4.7	6.0	7.3	8.6
9	2.8	4.1	5.2	6.3	7.4
SITE INDEX 80					
4	10.7	15.8	20.1	23.9	27.2
5	6.6	9.8	12.6	15.2	17.6
6	5.0	7.2	9.4	11.3	13.2
7	4.0	5.8	7.5	9.1	10.6
8	3.4	4.9	6.3	7.6	8.9
9	3.0	4.2	5.4	6.6	7.7
SITE INDEX 90					
4	11.6	16.8	21.2	25.1	28.5
5	7.1	10.4	13.3	15.9	18.4
6	5.3	7.6	9.8	11.8	13.7
7	4.2	6.1	7.8	9.5	11.0
8	3.6	5.1	6.5	7.9	9.2
9	3.1	4.4	5.6	6.8	8.0

Table 3.--Expected value growth percents for longleaf pine pulpwood over a 5-year period for intermediate and suppressed crown classes with a top diameter of 2.0 inches inside bark

D. b. h. (inches)	Crown ratio - percent				
	30	40	50	60	70
			Percent		
SITE INDEX 60					
4	--	5.3	10.8	15.3	19.2
5	0.9	4.4	7.5	10.2	12.8
6	1.4	3.8	6.0	8.0	9.9
7	1.6	3.4	5.1	6.7	8.2
8	1.6	3.1	4.5	5.8	7.1
9	1.5	2.8	4.0	5.1	6.2
SITE INDEX 70					
4	--	6.9	12.3	16.9	20.8
5	1.5	5.1	8.3	11.1	13.7
6	1.8	4.2	6.5	8.6	10.5
7	1.8	3.7	5.4	7.1	8.6
8	1.8	3.3	4.7	6.1	7.4
9	1.7	3.0	4.2	5.4	6.5
SITE INDEX 80					
4	1.4	8.3	13.8	18.4	22.4
5	2.1	5.8	9.1	12.0	14.6
6	2.1	4.7	7.0	9.1	11.1
7	2.1	4.0	5.8	7.5	9.1
8	2.0	3.5	5.0	6.4	7.7
9	1.8	3.2	4.4	5.6	6.8
SITE INDEX 90					
4	2.8	9.7	15.2	19.8	23.8
5	2.7	6.5	9.8	12.8	15.5
6	2.5	5.1	7.5	9.7	11.7
7	2.3	4.3	6.2	7.9	9.5
8	2.1	3.8	5.3	6.7	8.1
9	2.0	3.3	4.6	5.8	7.0

Table 4.--Expected value growth percents for longleaf pine pulpwood over a 5-year period for dominant and codominant crown classes with a top diameter of 3.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent				
	30	40	50	60	70
	- - - - - - Percent - - - - - -				
SITE INDEX 60					
4	13.5	19.8	25.0	29.5	33.4
5	6.8	10.1	13.0	15.7	18.2
6	4.8	7.1	9.2	11.1	13.0
7	3.8	5.6	7.2	8.7	10.2
8	3.2	4.6	6.0	7.2	8.4
9	2.8	4.0	5.1	6.2	7.3
SITE INDEX 70					
4	14.8	21.3	26.6	31.1	35.1
5	7.4	10.8	13.8	16.6	19.1
6	5.2	7.5	9.7	11.7	13.6
7	4.1	5.8	7.6	9.1	10.6
8	3.4	4.8	6.2	7.5	8.8
9	2.9	4.1	5.3	6.4	7.5
SITE INDEX 80					
4	16.1	22.6	28.0	32.6	36.7
5	8.0	11.5	14.6	17.4	20.0
6	5.5	7.9	10.2	12.2	14.1
7	4.3	6.2	7.9	9.5	11.1
8	3.6	5.1	6.5	7.8	9.1
9	3.0	4.3	5.5	6.7	7.8
SITE INDEX 90					
4	17.4	24.0	29.4	34.1	38.2
5	8.5	12.1	15.3	18.2	20.8
6	5.8	8.4	10.7	12.8	14.7
7	4.5	6.4	8.2	9.9	11.5
8	3.7	5.3	6.7	8.1	9.5
9	3.2	4.5	5.7	6.9	8.1

Table 5.--Expected value growth percents for longleaf pine pulpwood over a 5-year period for intermediate and suppressed crown classes with a top diameter of 3.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent				
	30	40	50	60	70
	- - - - - - Percent - - - - - -				
SITE INDEX 60					
4	--	8.9	16.2	22.1	27.0
5	1.4	5.4	8.9	12.0	14.7
6	1.7	4.3	6.6	8.7	10.7
7	1.8	3.6	5.4	7.0	8.6
8	1.7	3.2	4.6	6.0	7.2
9	1.6	2.9	4.1	5.2	6.3
SITE INDEX 70					
4	1.2	11.0	18.2	24.1	29.0
5	2.1	6.2	9.8	12.9	15.8
6	2.1	4.8	7.1	9.3	11.4
7	2.0	4.0	5.8	7.5	9.1
8	1.9	3.4	4.9	6.3	7.6
9	1.8	3.1	4.3	5.5	6.6
SITE INDEX 80					
4	3.3	13.0	20.2	26.0	30.8
5	2.8	7.0	10.7	13.9	16.8
6	2.5	5.2	7.7	9.9	12.0
7	2.3	4.3	6.2	7.9	9.5
8	2.1	3.7	5.2	6.6	8.0
9	1.9	3.3	4.5	5.7	6.9
SITE INDEX 90					
4	5.2	14.8	21.9	27.7	32.6
5	3.5	7.8	11.5	14.8	17.7
6	2.9	5.7	8.2	10.5	12.6
7	2.6	4.6	6.5	8.3	10.0
8	2.3	3.9	5.4	6.9	8.3
9	2.1	3.4	4.7	6.0	7.1

Table 6.--Expected value growth percents for slash pine pulpwood over a 5-year period for dominant and codominant crown classes with a top diameter of 2.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent		
	30	40	50
		Percent	
AVERAGE STAND D.B.H. - 2.0 INCHES			
4		26.6	29.0
5		20.5	22.5
AVERAGE STAND D.B.H. - 3.0 INCHES			
4		24.8	27.3
5		19.2	21.3
6		15.1	16.8
7		12.0	13.5
AVERAGE STAND D.B.H. - 4.0 INCHES			
4		22.8	25.5
5		17.9	20.2
6		14.2	16.0
7		11.4	12.9
AVERAGE STAND D.B.H. - 5.0 INCHES			
4	17.6	20.7	
5	14.1	16.6	
6	11.3	13.3	
7	9.1	10.7	
8	7.5	8.8	
AVERAGE STAND D.B.H. - 6.0 INCHES			
4	15.1	18.5	
5	12.6	15.2	
6	10.3	12.3	
7	8.4	10.1	
8	7.0	8.3	
9	5.8	7.0	
AVERAGE STAND D.B.H. - 7.0 INCHES			
6	9.2	11.3	
7	7.7	9.4	
8	6.4	7.9	
9	5.5	6.6	
10	4.7	5.6	
11	4.0	4.9	

Table 7.--Expected value growth percents for slash pine pulpwood over a 5-year period for intermediate crown class with a top diameter of 2.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent		
	30	40	50
		Percent	
AVERAGE STAND D.B.H. - 2.0 INCHES			
4		23.4	26.1
5		18.3	20.5
6		14.5	16.2
AVERAGE STAND D.B.H. - 3.0 INCHES			
4		21.4	24.2
5		17.0	19.2
6		13.6	15.4
AVERAGE STAND D.B.H. - 4.0 INCHES			
4		19.2	22.2
5		15.6	18.0
6		12.6	14.5
AVERAGE STAND D.B.H. - 5.0 INCHES			
4	13.2	16.8	
5	11.4	14.1	
6	9.5	11.6	
7	7.9	9.6	
AVERAGE STAND D.B.H. - 6.0 INCHES			
4	10.2	14.2	
5	9.7	12.6	
6	8.4	10.6	
7	7.2	8.9	
8	6.1	7.5	
AVERAGE STAND D.B.H. - 7.0 INCHES			
6	7.3	9.6	
7	6.4	8.2	
8	5.6	7.0	
9	4.8	6.0	
10	4.2	5.2	

Table 8.--Expected value growth percents for slash pine pulpwood over a 5-year period for dominant and codominant crown classes with a top diameter of 3.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent		
	30	40	50
	- - - - - Percent - - - - -		
AVERAGE STAND D. B. H. - 2.0 INCHES			
4		34.5	37.3
5		24.0	26.2
AVERAGE STAND D. B. H. - 3.0 INCHES			
4		32.3	35.3
5		22.6	24.9
6		16.9	18.8
7		13.2	14.7
AVERAGE STAND D. B. H. - 4.0 INCHES			
4		29.9	33.1
5		21.2	23.6
6		16.0	17.9
7		12.5	14.1
AVERAGE STAND D. B. H. - 5.0 INCHES			
4	23.4	27.4	
5	16.8	19.6	
6	12.8	15.0	
7	10.1	11.8	
8	8.1	9.6	
AVERAGE STAND D. B. H. - 6.0 INCHES			
4	20.3	24.6	
5	15.0	18.0	
6	11.7	13.9	
7	9.3	11.1	
8	7.6	9.1	
9	6.3	7.5	
AVERAGE STAND D. B. H. - 7.0 INCHES			
6	10.5	12.9	
7	8.5	10.4	
8	7.1	8.5	
9	5.9	7.1	
10	5.0	6.1	
11	4.3	5.2	

Table 9.--Expected value growth percents for slash pine pulpwood over a 5-year period for intermediate crown class with a top diameter of 3.0 inches inside bark

D.b.h. (inches)	Crown ratio - percent		
	30	40	50
	- - - - - Percent - - - - -		
AVERAGE STAND D. B. H. - 2.0 INCHES			
4		30.6	33.7
5		21.5	24.0
6		16.2	18.2
AVERAGE STAND D. B. H. - 3.0 INCHES			
4		28.1	31.5
5		20.0	22.6
6		15.2	17.2
AVERAGE STAND D. B. H. - 4.0 INCHES			
4		25.4	29.1
5		18.4	21.1
6		14.2	16.3
AVERAGE STAND D. B. H. - 5.0 INCHES			
4	17.7	22.4	
5	13.6	16.8	
6	10.8	13.1	
7	8.8	10.6	
AVERAGE STAND D. B. H. - 6.0 INCHES			
4	13.8	19.1	
5	11.7	15.0	
6	9.6	12.0	
7	8.0	9.8	
8	6.7	8.1	
AVERAGE STAND D. B. H. - 7.0 INCHES			
6	8.4	10.9	
7	7.2	9.1	
8	6.1	7.6	
9	5.2	6.5	
10	4.5	5.6	

APPLICATION OF STUDY RESULTS

The use of the results of this study requires a knowledge of the silvicultural characteristics of the species involved. The timber marker must be able to adjust the maturity limits shown in this paper for factors that could not be quantified in this study. Before considering biological and technical limitations of the study results, however, it is useful to consider financial maturity limits, disregarding such considerations.

The initial consideration in making use of these study results is to determine whether conditions on the ground are comparable to the conditions of this study. Once it is decided that the guides presented here can be used, it is necessary that the timber owner specify his alternative rate of return. With this knowledge the timber marker may develop simplified marking guides from the value growth tables (tables 2 to 9). Such guides are developed by comparing the owner's alternative rate of return to the value growth rates and then selecting the type of trees which delimit financial maturity. The timber marker should become familiar with the maturity limits for types of trees likely to be encountered in field practice. For example, in figure 1 the value growth rates for dominant and codominant longleaf pine (2.0-inch merchantable top) growing on land of site index 80 are related to diameter at breast height and crown ratio class. If the forest owner's alternative rate of return is 4 percent (as denoted by the heavy horizontal line) it can be seen

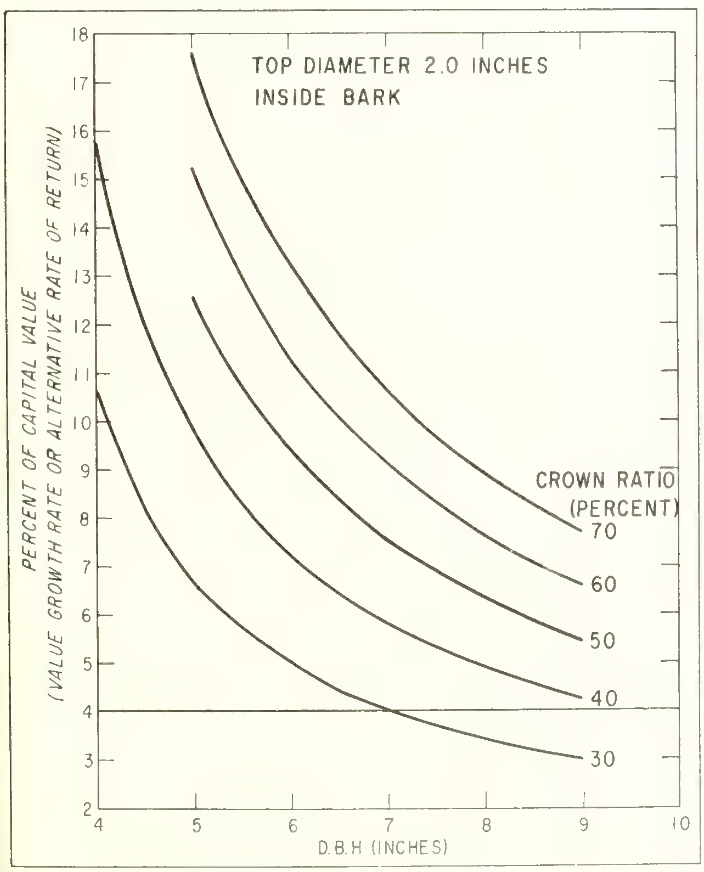

Figure 1.--Value growth rates of dominant and codominant longleaf pine on site index 80 land.

that trees 7 inches d.b.h. and larger would be financially mature if they had a crown ratio of 30 percent or less. If the alternative rate is 6 percent, trees 5.3 inches and larger with 30 percent crown ratio or less, those 6.8 inches and larger with 40 percent crown ratio or less, and trees 8.3 inches and larger with 50 percent crown ratio or less would be mature or overmature.

Slash pine guides are developed in a similar manner. In figure 2 the value growth rates of dominant and codominant slash pine in stands having an average d.b.h. of 6.0 inches are related to d.b.h. of the individual trees and crown ratio class. It is evident that if an alternative rate of 4 percent is applicable, no trees are financially mature within the limits of the data. If an alternative rate of 6 percent applies, trees 8.8 inches d.b.h. and larger with a crown ratio of 30 percent or less are mature.

Maturity limits for intermediate and suppressed trees occur at smaller diameters than for dominant and codominant trees (figures 3 and 4). For longleaf pine, a 4 percent alternative return indicates that all trees with a crown ratio of 30 percent or less and trees 7 inches d.b.h. and larger with a crown ratio of 40 percent and less are mature. In slash pine, a rate of 4 percent would not indicate maturity limits within the range of study results.

From these graphic presentations it is observed that the higher the crown ratio (vigor), and the lower the alternative rate of return, the higher will be the maturity limits defined in terms of tree d.b.h. The timber marker may work out simplified guides directly from the value growth tables and avoid constructing graphs by defining maturity limits in terms of one-inch d.b.h. classes.

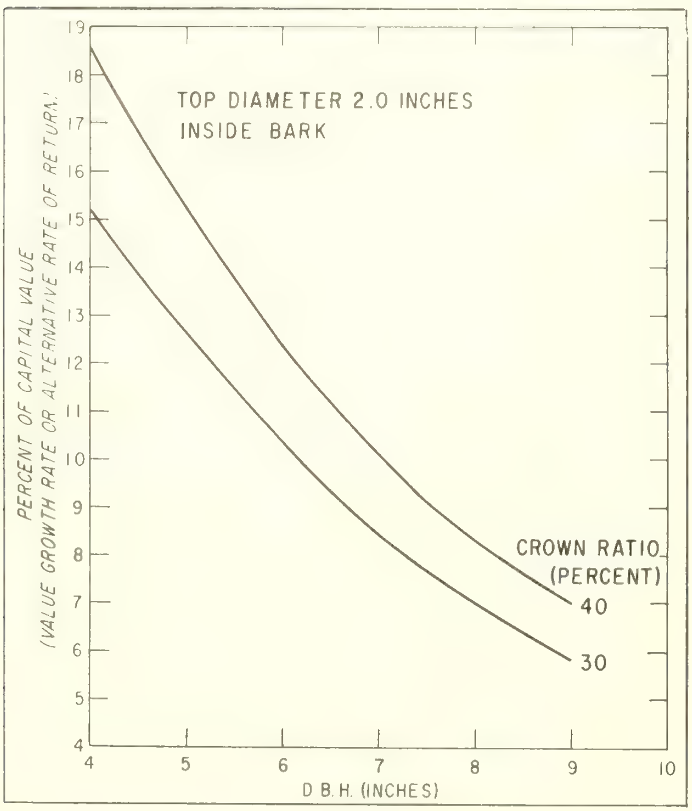

Figure 2.--Value growth rates of dominant and codominant slash pine in stands having an average d.b.h. of 6.0 inches.

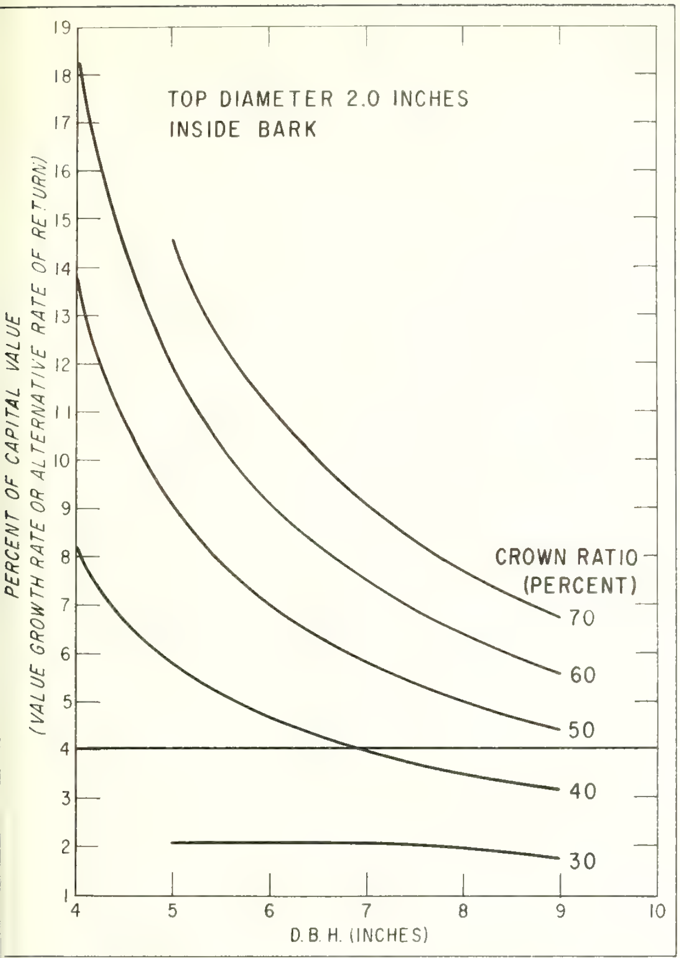

Figure 3.--Value growth rates of intermediate and suppressed longleaf pine on site index 80 land.

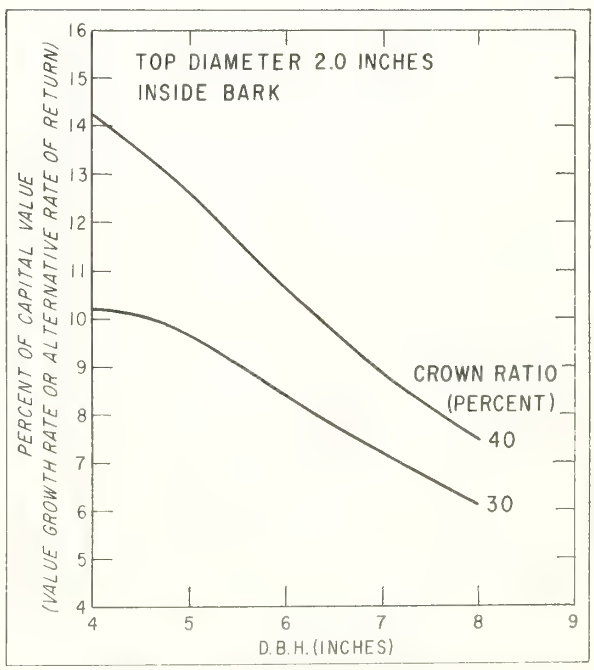

Figure 4.--Value growth rates of intermediate slash pine in stands having an average d.b.h. of 6.0 inches.

From the value growth tables for longleaf pine (tables 2 to 5), it can be seen that the better the site index, other factors being equal, the higher will be the predicted maturity limits. For example, with a 2-inch top limit, if an alternative rate of return of 6 percent applies and dominant and codominant trees with a crown ratio of 40 percent are considered, the maturity limits for site index classes 60, 70, and 80 would be the 7-inch d.b.h. class; but for site index 90 the limit would be the 8-inch diameter class (see table 2). All trees equal and larger in diameter than the maturity limit should be cut and the capital represented by such trees invested in alternatives yielding at or above the alternative rate of return.

Use of the slash pine value growth tables (tables 6 to 9) requires an estimate of average stand d.b.h. based on all trees one inch and larger in diameter before simplified marking guides can be constructed. The value growth rate decreases as average stand d.b.h. increases. Simplified marking guides may be constructed in the usual manner once average stand d.b.h. is estimated.

It is important to keep in mind that the guides presented here refer only to a single product, pulpwood. This restriction means that if a tree is expected to qualify as sawtimber or some other higher value product after a 5-year growth period, the value growth percents presented here are not applicable. The results of this study apply only to cases where the owner sells pulpwood on the stump.

It is necessary that the timber marker consider the effect of removing a given tree on the growth and development of nearby residual trees. These factors cannot be adequately quantified to be included in the financial maturity calculations, and must be judged by the timber marker on the basis of his experience before the marking decision is finally made. Silvicultural experience must be called upon when a group of competing trees earning just below the alternative rate of return is considered. Blindly following the value growth tables would indicate the entire group ready for harvest. The marker should, on the basis of his silvicultural knowledge of the species, estimate the increase in growth rate of residual trees which would result if one or more of the trees is removed. A more complete discussion of the need for tempering financial maturity guides with silvicultural knowledge may be found in Technical Bulletin 1146 by Duerr, Fedkiw, and Guttenberg.

The guides presented in this paper should be applied to thinning operations in even-aged longleaf and slash pine stands. The time at which the thinning is applied depends on factors independent of the financial maturity of the trees within the stands. There must be, of course, an adequate volume removed to justify a cutting operation. Insect and disease problems must be considered in timing thinnings if increased mortality is to be avoided. Market conditions must be analyzed to time cuts during a period when stumpage prices are to the owner's advantage. These and all other factors which normally enter into a decision concerning commercial thinning must be considered whether financial maturity guides are used or not. Financial maturity guides simply quantify certain factors, leaving fewer factors that must be considered in a subjective manner.

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The Effect of Hydrogen Peroxide on the Germination of Loblolly and Slash Pine Seed

by

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The Effect of Hydrogen Peroxide

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Germination of Loblolly and Slash Pine Seed 1/

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Introduction

Ching and others (2, 3, 5) have reported that dilute solutions of hydrogen peroxide have a pronounced promoting effect upon the germination of the seed of certain western conifers. Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) was particularly responsive. Seed soaked in 1 percent hydrogen peroxide for 48 hours reached 50 percent germination in $1\frac{1}{2}$ days, whereas seed stratified at 3° C. for 10 days required $8\frac{1}{2}$ days to reach 50 percent germination (2). Stimulations of this magnitude would be quite important in forest nursery and direct seeding operations because a large part of mortality occurs during the germination period (4). Increasing the speed of germination would shorten the time of vulnerability and should reduce mortality.

The current study was carried out to determine the effect of hydrogen peroxide upon the germination of loblolly (Pinus taeda L.) and slash (Pinus elliottii Engelm.) pine seed.

Experimental Procedure

All studies were carried out at the Eastern Tree Seed Laboratory 2/ located at the Georgia Forestry Center.

1/ This work was conducted while the senior author was employed by the Southeastern Forest Experiment Station, U. S. Forest Service, Macon, Georgia. He is now Assistant Forester, Auburn University, Auburn, Alabama. The junior author is Forester, Eastern Tree Seed Laboratory, U. S. Forest Service, Macon, Georgia.

2/ Operated in cooperation with Region 8 and Southeastern Forest Experiment Station, U. S. Forest Service; Georgia Forestry Commission; and Georgia Forest Research Council.

Each seed test consisted of duplicate samples of 100 seed placed in plastic dishes containing the germination medium. The medium was a 1 to 1, by volume, mixture of vermiculite and washed and sterilized sand. Seed were pressed firmly into contact with the medium and the dishes were watered, covered, and placed in germination rooms where automatic control of temperature and illumination period was maintained (fig. 1).

Figure 1.--Temperature and light were controlled automatically. Thermograph shows temperature in the alternating germination room.

Tests were conducted for 30 days. Germination counts were made every 2 days, starting on the third day for slash pine and the sixth day for loblolly pine. A seed was considered normally germinated when the radicle entered the medium and "erected" the seed coat. Abnormal germination was considered ungerminated. At the end of the germination period all ungerminated seed were cracked and germination figures were then expressed in terms of normal percent germination of full seed (fig. 2).

Stratification was accomplished by placing seed in a cloth bag, surrounded by wet peat moss, in a vented plastic container and storing the package at 36° to 38° F. for 30 days.

Experiment 1

Preliminary work indicated that concentrations of hydrogen peroxide greater than 3 percent were injurious to slash and loblolly pine seed. A soaking period of more than 96 hours also appeared to be detrimental.

Figure 2.--Ungerminated seed were recovered and cracked so the full seed percent germination values could be used in the analysis. This eliminated any error that could have been attributed to empty seed.

An experiment was designed to compare germination speed and magnitude of seed soaked in hydrogen peroxide, seed soaked in water, and seed stratified with that of untreated or dry seed. The treatments were as follows:

Treatment number	Treatment
1	Untreated seed
2	Stratified seed
3	Seed soaked 24 hours in water
4	Seed soaked 48 hours in water
5	Seed soaked 72 hours in water
6	Seed soaked 96 hours in water
7	Seed soaked 24 hours in 1 percent hydrogen peroxide
8	Seed soaked 48 hours in 1 percent hydrogen peroxide
9	Seed soaked 72 hours in 1 percent hydrogen peroxide
10	Seed soaked 96 hours in 1 percent hydrogen peroxide
11	Seed soaked 24 hours in 3 percent hydrogen peroxide
12	Seed soaked 48 hours in 3 percent hydrogen peroxide
13	Seed soaked 72 hours in 3 percent hydrogen peroxide
14	Seed soaked 96 hours in 3 percent hydrogen peroxide

The germination conditions were also varied. One group of treatments were germinated under alternating temperatures of 86° F. for 8 hours in the light and 68° F. for 16 hours in darkness. Another group was germinated at a constant temperature of 72° F. with 16 hours of light and 8 hours of darkness. The alternating temperature conditions approximated those used by Ching (2); the constant temperature conditions are standard at the Eastern Tree Seed Laboratory (1).

Three different seed lots were used for both slash and loblolly seed. Each lot was divided into two sublots, one for alternating temperature and one for constant temperature. From each sublot, 14 samples of approximately 200 seed were drawn at random (fig. 3). Each sample, except the samples to be stratified, was placed in a 250 ml. Erlenmeyer flask. At daily intervals, 200 ml. of the appropriate solution--water or hydrogen peroxide--were added to the flasks, starting with the 96-hour soakings on the first day, 72-hour soakings on the second day, etc. In this manner, all germination tests were begun on the same day. The stratified samples were drawn 30 days prior to the start of the germination test so that germination of this test was begun on the same day as the other tests.

Experiment 2

A second experiment was designed to study the effect of volume of peroxide solution, storage after treatment, and frequent changing of solution upon the germination rate of loblolly pine seed. A 1 percent solution of hydrogen peroxide was used for all of the treatments. There were 3 soaking periods--24, 48, and 72 hours; two volumes of solution--25 ml. and 100 ml. per 100 seed; solutions were changed daily in half the treatments and un-

changed in the other half; samples from each treatment were set up for germination immediately or surface-dried and stored 3 days at 38° F. All treatments were duplicated and germinated at a constant temperature of 72° F. with 16 hours of daylight and 8 hours of darkness per day.

Figure 3. --Seed were randomly selected with a vacuum seed counter.

Results

Experiment 1

With loblolly pine, the germination data for the 10th and 30th days after the start of the germination tests were analyzed. For slash pine, the data from the 7th and 30th days were used. The 7th and the 10th days after the start of the tests represent the points where approximately 50 percent of the total germination had occurred for slash pine and loblolly pine, respectively. The germination of both species was essentially complete by the 30th day. By using the two sets of figures, both the speed and extent of germination could be studied.

The full-seed germination percentage was calculated for each observation and the percentages were transformed by $\arcsin\sqrt{\text{percent}}$ (6). An analysis of variance was then performed upon the transformed values (table 1).

The germination rates for loblolly seed were not affected by germination conditions; however, the germination rates for slash seed were significantly lower under alternating temperature conditions than they were under constant temperature conditions (tables 1 and 2).

Differences between treatments were highly significant at both times of observation for each species. Significance at the 1 percent level was apparent between the three soaking solutions (water, 1 percent hydrogen peroxide, and 3 percent hydrogen peroxide) at all times of observation.

Single degree of freedom breakdown of the effects of solutions indicated that hydrogen peroxide treatment was vastly superior to water. The 1 percent solution of hydrogen peroxide was superior to the 3 percent solution in every instance except the final readings for slash seed.

The linear component and the main effect of soaking periods were highly significant in the slash pine data but unsignificant in the loblolly. Most of this effect may be because increased soaking time in water sharply decreased the germination of slash seed. The interaction between soaking period and solution was also highly significant with the most significant component being the interaction of the linear component of soaking period with the water versus hydrogen peroxide component of the solution effect.

The average of stratified plus unstratified treatments was significantly less than the average of all other treatments for the 7th- and 10th-day observations for slash and loblolly, respectively. These effects were not significantly different at the time of the final germination counts. The soaking treatments significantly increased the speed of germination over the average of stratified plus unstratified but did not increase the total germination.

Table 1.--Analyses of variance for experiment 1

Source	Degrees of freedom	Mean squares 1/			
		Loblolly		Slash	
		10th day	Final	7th day	Final
Reps	2	102.21	326.62	4391.08**	6547.04**
Germination conditions	1	163.85	747.66	491.76*	313.35*
Error "a"	2	320.78	87.66	8.16	16.15
Treatments	13	328.61**	88.80**	390.66**	358.24**
Between solutions (S)					
(H_2O, 1 percent H_2O_2, 3 percent H_2O_2)	2	1083.41**	306.80**	1546.46**	1195.18**
(1) H_2O vs. average of H_2O_2	1	1761.95**	263.78**	2891.74**	2348.69**
(2) 1 percent H_2O_2 vs. 3 percent H_2O_2	1	404.88**	349.81**	201.17*	41.67
Soaking period (T)	3	140.22	58.79	261.26**	407.49**
(a) Linear	1			689.18**	1128.58**
(b) Quadratic	1			67.13	4.92
(c) Cubic	1			27.47	88.98
S X T	6	32.47	51.36	175.94**	105.06**
(1) x (a)	1			826.66**	451.66**
(1) x (b)	1			6.11	5.52
(1) x (c)	1			13.31	8.86
(2) x (a)	1			49.26	87.80
(2) x (b)	1			160.19*	75.95
(2) x (c)	1			0.10	0.75
Unstratified and stratified vs. other treatments	1	251.34*	0.42	126.07*	6.90
Unstratified vs. stratified	1	1238.26**	55.81	20.22	406.97**
Conditions x treatments	13	41.59	16.76	70.54*	74.16*
Error "b"	52	57.74	32.83	30.11	33.11
Sampling error	84	8.16	10.46	10.75	14.78

1/ Single degree of freedom breakdowns not shown for nonsignificant main effects.

* Indicates significance at the 5 percent level.
** Indicates significance at the 1 percent level.

Table 2.--Germination means under the different germination conditions

Germination conditions	Loblolly		Slash	
	10th day	Final	7th day	Final
Constant temperature 72° F. - 16 hrs. light	54.4	82.9	64.7	76.9
Alternating temperature 86° F. - 8 hrs. light 68° F. - 16 hrs. dark	57.8	77.1	59.2	72.5

Stratified loblolly seed exhibited a significantly higher germination than unstratified on the 10th day of germination but not on the final day, indicating a typical response to stratification. Stratification had no effect upon the germination of slash seed on the 7th day of germination but produced a significant reduction in the total germination (tables 1 and 3). It is not uncommon for stratification to have a detrimental effect upon germination of slash seed (1).

There were no significant interactions between germination conditions and treatments in the loblolly data. However, this interaction was significant in the slash data. One of the slash pine seed lots was a particularly poor lot having an average germination of 56 percent, compared to 82 percent and 85 percent for the other two lots. The erratic response of this one poor lot resulted in a highly significant difference between lots and greatly contributed to the significant interaction between treatments and germination conditions. Stratified seed from the poor lot germinated better under alternating temperatures than under constant temperature conditions, whereas with peroxide-treated seed the reverse was true. No other trends were obvious, which might explain the significance of the interaction.

Table 3.--The treatment means averaged over replications and germination conditions for experiment 1

Treatment	Loblolly		Slash	
	10th day	Final	7th day	Final
Unstratified	1/ 38.9	82.6	57.1	80.8
Stratified	62.7	77.6	59.8	68.9
Water - 24 hours	45.9	78.9	64.6	78.0
Water - 48 hours	48.0	79.0	55.0	67.5
Water - 72 hours	50.5	78.4	50.6	64.6
Water - 96 hours	50.0	72.9	38.7	53.8
Average for water	48.6	77.3	52.2	66.0
1 percent hydrogen peroxide - 24 hours	56.2	81.9	69.4	83.0
1 percent hydrogen peroxide - 48 hours	66.1	84.3	73.2	81.3
1 percent hydrogen peroxide - 72 hours	65.6	83.9	73.1	80.9
1 percent hydrogen peroxide - 96 hours	70.1	85.8	63.9	73.5
Average for 1 percent	64.5	84.0	69.9	79.7
3 percent hydrogen peroxide - 24 hours	54.2	82.7	65.9	80.5
3 percent hydrogen peroxide - 48 hours	59.0	81.4	64.3	76.7
3 percent hydrogen peroxide - 72 hours	61.2	76.2	65.1	78.6
3 percent hydrogen peroxide - 96 hours	56.8	74.8	66.6	77.2
Average for 3 percent	57.8	78.8	65.5	78.3

1/ All figures are percent germination of full seed.

Experiment 2

An analysis of variance was performed upon the full seed germination percent values after transformation to arcsin. Germination percentages for the 9th and final (30th) days of the tests were used.

The only significant comparison on the 9th day of germination was the difference between seed germinated immediately after treatment and seed stored 3 days before the start of germination (tables 4 and 5). When germination was complete, the effect of storage was no longer apparent, indicating that storage for 3 days destroyed the stimulating effect of hydrogen peroxide upon the speed of germination but did not reduce the total germination.

The interaction between length of the soaking period and volume of peroxide solution was significant on the final day of germination. With 48 or 72 hours of soaking, the lower volume (25 ml./100 seed) was equal to the higher volume (100 ml./100 seed), but with a 96-hour soak, there was a depressing effect of the lower volume (table 6).

Discussion and Conclusions

The results reported here are in general agreement with those reported previously for other species (2, 3, 5) and indicate that soaking in 1 percent hydrogen peroxide solution may be a suitable substitute for stratification to increase the speed and uniformity of germination of loblolly and slash pine seed. In some instances the total germination of loblolly pine may be increased by treatment with hydrogen peroxide.

For loblolly pine seed, a 48- to 96-hour soak in 1 percent hydrogen peroxide was the most successful treatment. The 24-hour soak was definitely inferior to the longer treatments. With slash pine seed, however, the 24-hour treatment was equal, or superior, to the longer exposures to 1 percent H_2O_2. The difference in response between the two species probably is caused, in part, by differences in the thickness of the seed coats of the two species. Loblolly pine possesses a much heavier seed coat than slash pine and the peroxide may not penetrate to the interior of loblolly pine seed as rapidly as it does in slash pine.

The 1 percent solution of hydrogen peroxide was superior to the 3 percent solution in nearly every instance. The longer soakings in 3 percent solution appeared more damaging to loblolly pine seed germination than to slash pine seed. Preliminary studies indicated that soaking in 5 percent and 10 percent hydrogen peroxide solutions for just a few hours may be lethal to both species, and prolonged soakings in 3 percent solution may drastically reduce germination.

Table 4.--Analysis of variance for experiment 2

Source	Degree of freedom	Mean square	
		9th day [1]	Final [2]
Solution change vs. solutions not changed (C)	1	55.06	0.05
Soaking period (D)	2	40.87	14.98
Storage (S)	1	[3]712.17	7.93
Volume (V)	1	16.98	19.88
C x D	2	62.37	7.20
C x S	1	48.43	24.29
C x V	1	0.25	5.67
D x S	2	50.52	5.33
D x V	2	2.60	[4]32.26
S x V	1	2.04	3.68
Error {C x D x S, C x D x V, C x S x V, D x S x V, C x D x S x V}	9	32.48	7.06 [5]6.83
Sampling error	24	7.12	6.74
Total	47		

1/ All M. S. tested against pooled value of 3rd and 4th order interactions termed "Error."
2/ All M. S. tested against pooled value of "Error" plus Sampling error.
3/ Significant at 1 percent level.
4/ Significant at 5 percent level.
5/ Pooled error term.

Table 5.--The effect of storage after treatment upon the germination of seed soaked in 1 percent hydrogen peroxide

Treatment	Percent germination
No storage	[1]52.5
Stored 3 days at 38° F.	39.3

1/ Figures represent germination on the 9th day and were significantly different at the 1 percent level.

Table 6.--The effect of length of soaking and volume of solution of 1 percent hydrogen peroxide upon the germination of loblolly pine seed

Volume per 100 seed	Soaking period		
	48 hours	72 hours	96 hours
25 ml.	1/ 85.8	85.1	80.1
100 ml.	86.4	83.5	86.6

1/ Figures represent mean germination percentage values on the final (30th) day of germination. The interaction of the two factors was significant at the 5 percent level.

A daily change of the peroxide solution and different volumes of solution had no significant effect upon the germination of loblolly pine seed. There was a significant interaction, however, between the length of the treatment period and solution volume, indicating that the use of the higher volume yielded higher germination rates when the seed were subjected to prolonged soaking.

The detrimental effect of storage following hydrogen peroxide treatment was not surprising, but the magnitude of the effect was greater than had been anticipated. Evidently the stimulating effect of hydrogen peroxide is short lived and is lost in a very short time in cold storage.

It appears that for a nursery or direct seeding operation, a 1-day soak for slash and a 2- or 3-day soak for loblolly pine in 1 percent hydrogen peroxide should be best. Between 4 and 5 gallons of solution would be needed per pound of seed. The seed would have to be sowed within a few hours after removal from the hydrogen peroxide solution, and it might be preferable to leave the seed in peroxide for an additional 24 hours if conditions were not suitable for sowing at the end of the original treatment period.

Current studies are attempting to develop a practical procedure for the use of hydrogen peroxide treatment in a nursery operation. One of the factors difficult to evaluate is the cost of hydrogen peroxide treatment. If purchased in bulk quantities, technical grade 30 percent hydrogen peroxide costs approximately 20 cents per pound. At this rate, treatment with hydrogen peroxide would cost around 5 cents per pound of seed for peroxide alone. The cost of labor cannot be estimated until a suitable nursery procedure is developed. It appears that the cost of hydrogen peroxide treatment would not be prohibitive.

Summary

The effect of hydrogen peroxide upon the germination of slash and loblolly pine seed was studied. A 48- to 96-hour soak in 1 percent hydrogen peroxide increased the speed of germination of loblolly pine seed to the point where it equalled that obtained by stratification. However, this treatment had no effect upon the total germination. Soaking the slash pine seed in 1 percent hydrogen peroxide for 24 to 48 hours increased both the rate and extent of germination beyond that of stratified seed. Changing the peroxide solutions daily and varying the solution volume did not alter the stimulating effect of the H_2O_2, but storage of the seed at 38° F. for 3 days following treatment produced a significant reduction in the germination rate.

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Diseases in Southeastern Forest Nurseries and their control

by

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Much of the information in this handbook was obtained while the author was a nursery specialist working under USDA Soil Bank funds in cooperation with the North Carolina and South Carolina Divisions of Forestry, and the North Carolina Agricultural Experiment Station. Many of the disease control methods as well as new knowledge about southern nursery diseases resulted from the author's association with Dr. A. A. Foster, of the U. S. Forest Service, whose work at the time was supported in part by the Forestry Commission of the State of Georgia and the Georgia Forest Research Council. Important among major contributors to knowledge of nursery diseases have been P. V. Siggers, Berch W. Henry, R. M. Lindgren, and Felix Czabator of the Southern Forest Experiment Station, and Samuel J. Rowan, of the Southeastern Station.

COVER PHOTO:

The Little River Nursery of the North Carolina State Division of Forestry at Goldsboro. Its fumigated beds produce uniform, healthy stock.

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INTRODUCTION

The large increase in planting forest trees in the United States during the last 10 years has resulted in a tremendous increase in the demand for planting stock. This demand has been exceptionally heavy in the South, where favorable growing conditions and the use of fast-growing species have made forest farming a profitable business. Seedling production in southern nurseries increased from 400 million in 1955 to more than a billion in 1959. Although the closing of the Soil Bank Program has curtailed production considerably, seedling demand during the next few years is expected to remain high since thousands of acres of land still need restocking.

The increased production of seedlings, often accomplished by increasing the seedling density on existing nurseries, brought about a new awareness of disease problems. Now that production has been lowered somewhat, losses from diseases, insects, and poor agronomic practices must be kept as low as possible to keep down the price per thousand seedlings.

This handbook gives descriptions and control of the more common diseases of seedlings of forest trees occurring in southern nurseries. It is divided into four major parts: (1) disease descriptions and specific control measures, (2) general methods and techniques involved in controlling the diseases, (3) list of chemicals and formulations used to control the diseases, and (4) names and addresses of chemical manufacturers.

Damping-off

Damping-off is probably the most widespread disease of forest tree nursery stock and occurs to some degree in almost all nurseries. It is primarily a disease of coniferous seedlings, although many hardwood species may be affected.

Numerous fungi may cause damping-off. *Fusarium* spp. appear to be most commonly associated with this disease in southern nurseries. Other fungi, especially *Rhizoctonia solani* on yellow-poplar and *Pythium* spp. on longleaf pine, may also cause heavy losses.

The term damping-off describes a group of symptoms rather than one particular disease. Three kinds of damping-off are generally recognized. In *pre-emergence* damping-off, the seed itself is decayed or the seedling is killed before it emerges from the soil. Often this loss is blamed on poor seed, since it is difficult to determine whether or not the seeds were viable if the seedlings did not emerge. The presence of germinated seed with decayed radicles is a good indication of *pre-emergence* damping-off.

In *post-emergence* damping-off, the seedlings are affected after they appear above the ground. In most instances, they are attacked at or slightly above the soil line. The first symptom is a brown lesion at the root collar. The stem at this point is rapidly girdled and the infected seedling topples over. This type of damping-off is sometimes confused with heat lesions, which usually appear $\frac{1}{2}$ to 1 inch above the ground line and are whitish in color, compared to the brownish decayed tissue at the ground line in the case of damping-off.

During long periods of high humidity, some fungi may attack the tops of seedlings, resulting in what is termed *top damping-off*. In many such instances, the roots are not affected.

The fungi that cause damping-off are, for the most part, common soil inhabitants and are able to survive in the soil in the absence of a host plant. They do not usually cause disease unless conditions for their development are favorable or conditions for the growth of seedlings are poor. Consequently, damping-off can usually be kept to a low level by manipulating the environmental conditions in which the seedlings are growing. The following practices are recommended for keeping losses from damping-off to a minimum:

1. Choose a well-drained site for the nursery.
2. Plant after soil temperature is above 60° F.
3. Keep soil pH level at 6.0 or below.
4. Avoid dense stands.
5. Maintain a low level of nitrogen until the seedlings are beyond the damping-off stage (usually about 6 weeks old).
6. Turn under cover crops at least 2 months before seeding.
7. Use only enough mulch to conserve moisture.

In most cases damping-off in southern forest nurseries makes its appearance and runs its course in a very short time. For this reason, there is rarely much to be gained by attempts at chemical control once the disease is discovered. Several fungicides such as Thiram,[1] Captan, or PCNB can be drenched into the soil, but the effects of these treatments are only temporary, and their effectiveness questionable when applied after the disease appears. Where damping-off is causing losses consistently over a period of years, treating the seed with Thiram will lower the incidence of the disease. Seed treatments, however, usually lower germination from 5 to 15 percent. Damping-off can also be controlled effectively by the use of preplant soil fumigation with an all-purpose soil fumigant, but the expense is hardly warranted unless other problems such as weeds, root-rot, or nematodes are causing considerable injury, and the cost of treatment can thus be prorated over multiple benefits.

Root-Rot

Like the term damping-off, root-rot is a general term rather than a distinct disease. Root-rots can be caused by a number of different fungi. In many instances, fungi that cause damping-off will continue to be active after the seedlings have developed stiff stems and cause death of the seedlings. Such damage is usually referred to as late damping-off or early root-rot. In general, small roots are the first to be attacked by root-rot fungi. The first noticeable symptom is a blackening or reddening of the infected roots. These roots die, and in severe cases, the disease progresses to include the larger roots. Top symptoms are not always correlated with degree of root damage because seedlings in the nursery are usually not under any stress for water or nutrients. A large portion of the roots may be destroyed before any stunting or chlorosis of the tops is observed. When put under stress in the outplanting site, however, badly root-rotted seedlings do not survive.

Root rots generally become increasingly severe over a period of years, especially when several successive crops are grown on the same area. Their development is often so slow that the gradual decline in the quality of the seedlings is scarcely noticeable, especially if the disease occurs throughout the nursery. In such a case, the disease can only be detected by careful removal of the seedlings from the soil and examination of the root systems. Fumigation of small plots with an all-purpose soil fumigant and comparison of seedlings from the fumigated and non-fumigated soil is a good method to use in detecting damage caused by root rots.

One of the most serious and distinctive root rots which occur in southern nurseries is known as black root-rot. It has been identified from at least 10 southern nurseries and may occur in more. All species of southern pine are susceptible. In the early stages, it is impossible to distinguish from other root rots. Later, however, characteristic reddish-black swellings may be noted on the taproot and larger laterals. These swellings may be localized or in severe cases cover the entire taproot. The disease is most severe

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1/ The mention of trade products does not imply endorsement by the U. S. Department of Agriculture over similar products not named.

during periods of high temperature. In early fall, numerous new roots appear just below the ground line. These roots may help the seedlings survive during the fall "hardening-off" period, but survival of these seedlings in the field is often poor. Black root-rot is caused by a complex of organisms, the most important of which are Sclerotium bataticola and Fusarium spp. Although nematodes are also believed to be a part of the complex, their role has not been determined.

Other damaging root rots that occur in southern forest nurseries are: Cylindrocladium scoparium on white pine, yellow-poplar, and Fraser fir; Pythium sp. on longleaf pine; Phytophthora cinnamomi on black walnut and yellow-poplar; and Rhizoctonia solani on yellow-poplar.

Preplant fumigation with a complete soil fumigant is the best control for root rots. Drenching with fungicides is impractical over a large area and, at best, gives only temporary control of the disease.

Nematodes

Nematodes are microscopic eel-shaped animals which feed on the roots of plants. Like root rots, nematodes seldom cause spectacular losses, but often become increasingly severe over a period of time. Often the increase in population of parasitic nematodes is so gradual that the damage they cause is not easily noticeable. However, they can cause severe damage, especially to small seedlings.

The typical symptoms of nematode injury are a general decline, stunting, and chlorosis of the seedlings. The brilliant yellow color of affected seedlings is very distinctive and easy to distinguish from the light yellow-green color of nitrogen-deficient seedlings, and the creamy-white color of those that are iron-deficient. Nematode injury may be scattered among the seedbeds, but more often is confined to localized spots. The small rootlets of the seedlings usually become necrotic. On very small seedlings, the roots may look as though they had been clipped off, and have small rounded knobs on the ends of the roots. On hardwood seedlings, the root knot nematode may cause swellings all along the roots.

Damage to the roots by the feeding of nematodes often results in attack by soil fungi. The resulting root-rot and nematode complex may cause considerable damage.

Since nematodes are usually microscopic in size, it is impossible to diagnose nematode injury without special techniques and a knowledge of the nematodes themselves. For this reason, soil and root samples must be sent to someone with facilities to make determinations for the presence of nematodes. Some state universities have such facilities. Soil samples should be taken from the root zone of seedlings within the affected area, on the margin of the affected area, and in adjacent healthy areas. These samples should be collected in much the same way that soil samples are taken for fertilization recommendations; that is, several small samples should be taken at random

in the collecting area, pooled and mixed thoroughly. At least a 1-pint sub-sample is then drawn and placed in a plastic bag for shipment. Root specimens should also be placed in plastic bags.

There are several fumigants available for the specific control of nematodes. The most common are dichloropropane-dichloropropene (DD), ethylene dibromide (EDB), and 1,2-dibromo-2-chloropropane (DBCP). DD and EDB must be used as preplant treatments with effective rates of 25 gallons and 15 gallons per acre, respectively. DBCP is the only material that can be used on living seedlings, but must be used only in the diluted form, since the concentrate is toxic to seedlings. Four to six gallons per acre usually give good control.

All-purpose soil fumigants will also control nematodes, but if nematodes are the only problem, a simple nematocide is more economical to use.

Cylindrocladium Blight

Cylindrocladium blight, caused by *C. scoparium*, is the most important seedling disease of white pine. This fungus may cause damping-off, root-rot, needle blight, and stem cankers, but the most spectacular and damaging aspects of the disease are the needle blight and stem cankers of 2-0 seedlings. Needle blight usually appears during middle or late summer. Initial infection takes place near the tip and progresses toward the base of the needle. The first symptom is yellowing of infected tissue, but the color rapidly changes to a brick red. Severely affected beds appear as if they have been scorched by fire. The dead needles are usually shed during fall and winter. The buds are not usually affected, and if no stem cankers occur, the seedlings will put out new needles the next spring and resume growth.

Stem canker is the most serious aspect of this disease. Cankers may occur at any point on the stem, but usually originate at the base of needle fascicles. The first symptoms are brownish areas which gradually enlarge and become slightly sunken. In some instances, the canker may be walled off by callus growth; more frequently, however, the canker enlarges until the stem is girdled. The entire plant then takes on the brick-red color which is characteristic of the needle blight phase and finally dies. The needle blight phase of Cylindrocladium blight is sometimes confused with a needle cast caused by an unidentified fungus. The needle cast symptoms usually become apparent in September or October, much later than those of Cylindrocladium. The needle cast fungus affects only the needles. Other than the time of appearance, the only way to distinguish the two diseases is by isolating the causal fungi.

Control of Cylindrocladium blight is very difficult. The fungus is soil-borne and produces a stage resistant to normal rates of methyl bromide. At least 500 pounds per acre and sometimes more are required to give adequate control. The needle blight phase of the disease can be kept in check by using ferbam at the rate of 2 pounds per acre in a regular spray schedule. The spray should be applied at a high pressure in order to insure adequate needle coverage. Stem cankers are more difficult to control because the dense

needles of 2-0 seedlings prevent adequate coverage of the stem. Hence it may be advantageous to increase the volume to 300 to 400 gallons per acre so that the excess spray will run down the stems of the seedlings. The same spray schedule will also control the needle cast disease.

Fusiform Rust

Fusiform rust, caused by the fungus *Cronartium fusiforme*, is potentially the most serious disease of pine seedlings in southern forest nurseries. Although infected seedlings rarely if ever die in the nursery, they survive only a short time after being outplanted.

The early symptoms of fusiform rust are very difficult to detect. They consist of tiny purple spots on the needles or stems of small seedlings. The typical spindle-shaped gall or swelling on the stem of the seedling is usually not evident until late summer. These galls are found normally near the ground line, but occasionally occur up to six inches high on the stem when late infection takes place. In some instances, galls may not be produced on infected seedlings until late the following spring, hence making it impossible to remove all infected seedlings shipped from the nursery during fall and winter. Excessive basal branches are sometimes indicative of infection by fusiform rust, but this is not a reliable characteristic in diagnosing this disease.

The fungus which causes fusiform rust requires oak, as well as pine, to complete its life cycle. Water oak and several species of the red oak group are the most susceptible and most common alternate hosts. Oak leaves are infected by spores produced on infected pine in the spring shortly after the oak leaves emerge. About 2 weeks later, spores are formed on the oak, which then infect pine. Pine seedlings are liable to infection immediately after they emerge from the soil until weather conditions become unfavorable for infection to take place, usually in June.

Weather conditions greatly influence infection of pine by the fusiform rust fungus. Periods of 18 hours or more of saturated atmosphere and temperatures between 60° and 80° F. are necessary for the abundant infection of pine seedlings. Since these conditions seldom occur after July 1, seedlings are relatively safe from infection after that time, and spraying to control the disease can be terminated. Fusiform rust can be controlled to $\frac{1}{2}$ of 1 percent infection in the Southeast by weekly applications of ferbam at the rate of 2 pounds per 75 gallons of water per acre. During periods of rapid growth, however, applications should be made more frequently to keep the new growth protected.

Brown Spot

Brown spot is caused by the fungus *Scirrhia acicola*. Although this fungus is capable of causing a serious needle disease of large trees of loblolly and white pines, it is a problem in the nursery only on longleaf pine and occasionally slash pine.

The initial symptoms of brown spot are straw-colored spots on the needles. These spots later turn light brown and are bordered by deep brown zones which may become purple during cool weather. Another type of symptom known as "bar spot" initially appears as an amber-yellow band that encircles the needle. Later, a brown band may appear in the center of the yellow band. The fungus usually sporulates in the center of the spot or on dead portions of the needles.

Although brown spot may occur in the nursery as early as May or June, it is most serious in late summer and fall. In the states from Georgia northward, brown spot is seldom a serious problem in the nursery. The fungus can be easily controlled by periodic spraying with Bordeaux mixture. Since this disease continues to develop in the outplanting site, it is good practice to make the final spray application just before lifting.

Rhizoctonia Needle Blight

During extended periods of moist, cool weather, the Rhizoctonia fungus may cause top killing of many species of conifers. New growth is most susceptible to attack. The symptoms are almost identical to those caused by *Cylindrocladium scoparium* on white pine foliage. On longleaf pine the fungus first attacks the needles near the soil line and eventually moves into the bud and crown, causing death of the seedling. The mycelium of the fungus can be seen as fine brown threads. These are often numerous enough to mat the dead needles together.

For longleaf pine, the best control is to clip the needles. This permits good aeration and lowers humidity near the ground line, where the fungus is most active. Withholding irrigation may also help to keep the disease in check. Spraying with fungicides is usually not necessary. If needed, however, Terrachlor at the rate of 50 pounds per acre is the best to use. Spraying should be followed by at least $\frac{1}{2}$ inch of water.

Phomopsis Blight

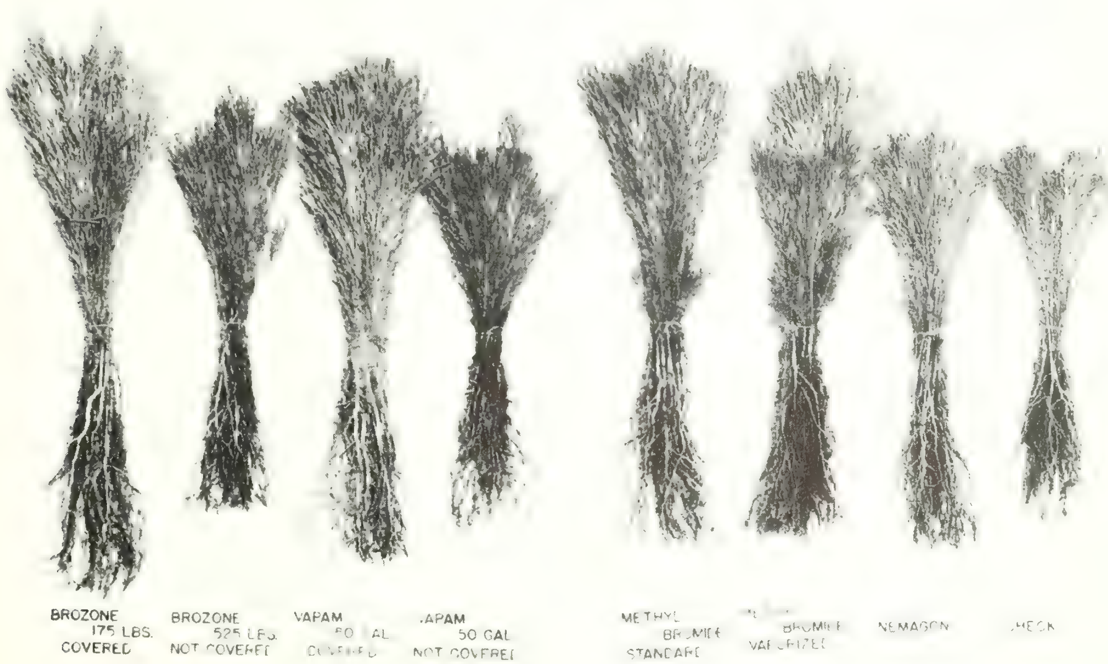
Phomopsis blight, caused by the fungus *Phomopsis juniperovora*, is the most serious disease of eastern redcedar and Arizona cypress seedlings. The distinguishing symptom of the disease is the death of branch tips or sometimes the entire tops of the seedlings. The fruiting bodies of the fungus appear as numerous small, black spots on recently killed needle or stem tissue. During moist periods, the spores are extruded from the fruiting body and are spread to nearby plants by splashing rain or irrigation water.

Fungicides containing mercury appear to be the most effective in controlling Phomopsis blight. The most commonly used formulations are Puritized Agricultural Spray and Merbam. Under southern conditions, Merbam appears to be the most effective. Sprays should be applied every 7 to 10 days throughout the growing season. During periods of moist, cool weather, twice-weekly applications may be necessary.

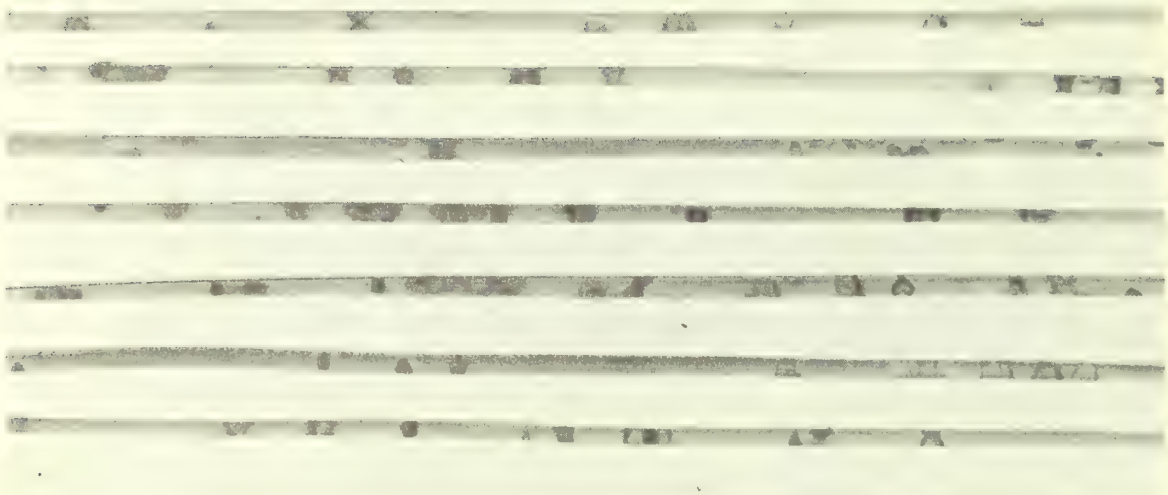
Fusiform rust swellings near ground line of 1-0 loblolly pine seedlings.

Left, seedling stunted by black root-rot. Center, seedling with healthy roots. Right, seedling almost denuded of roots by black root-rot, with the additional roughened root swelling characteristic of this root-rot.

Slash pine beds in a southeastern nursery. The foreground of the three central beds was not fumigated, since the plastic covers did not quite cover these beds entirely. The remainder of these beds was fumigated with Brozone. Note the difference in size, quality, and uniformity of seedlings following fumigation.

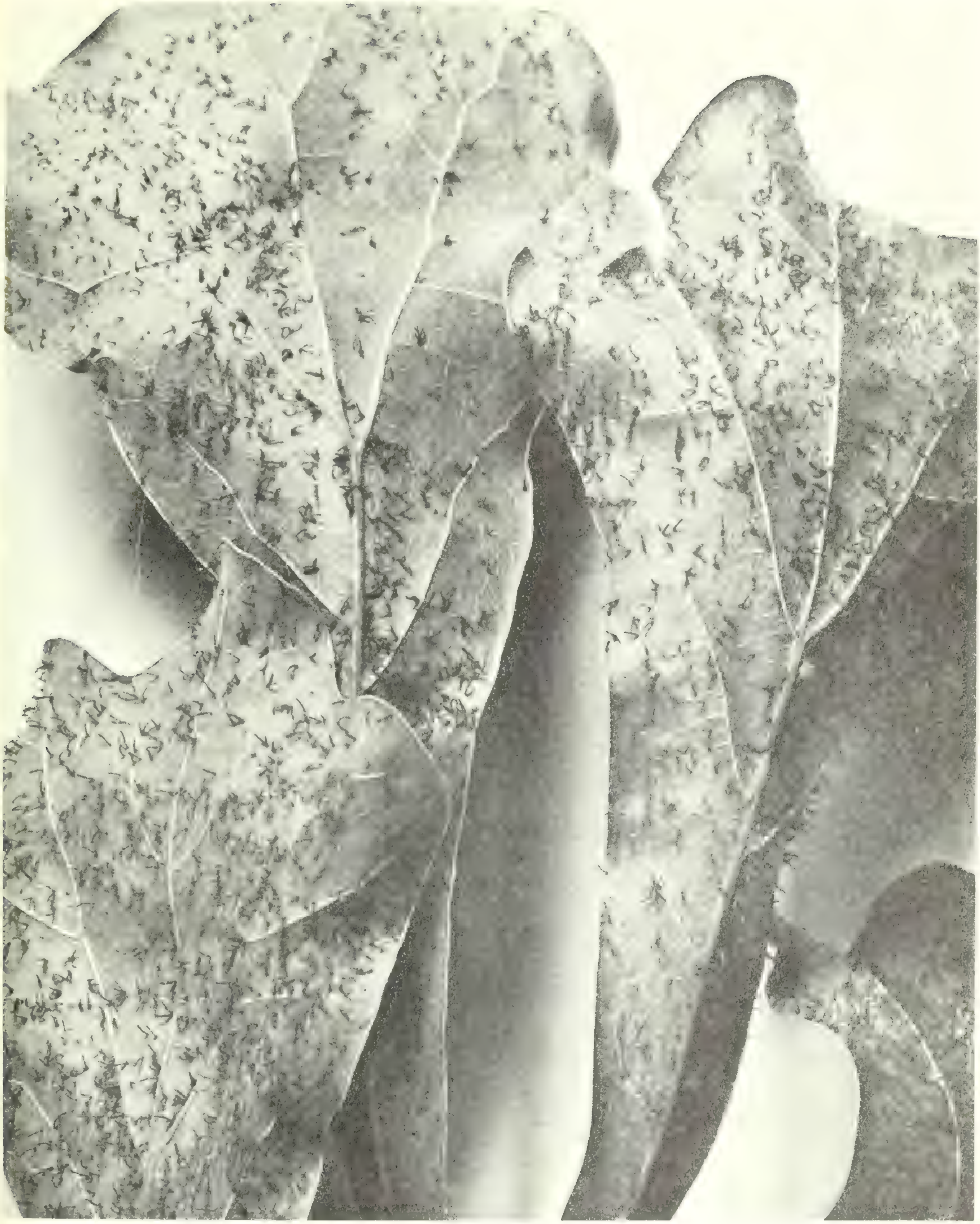


Loblolly pine seedlings from nursery beds given soil treatments as indicated. Each bundle contains 25 seedlings pulled at random from a given bed.



Brown spot lesions on longleaf pine needles. These are sometimes called bar-spots.

Slash pine seedlings. Left, roots destroyed entirely by the stunt nematode, *Tylenchorhynchus claytoni*; center, roots partially destroyed by this nematode; right, a healthy seedling.



Telia of fusiform rust on a water oak leaf. These hairlike structures on the under side of oak leaves produce the spores that infect pines. In this stage, fusiform rust cannot be separated easily from several other rust fungi.

It is important to cull all infected seedlings at lifting, since seedlings with only a single infected branchlet have little chance of survival after transplanting. There is also the possibility of spreading the fungus to other seedlings in the shipping bundle.

Cercospora Blight

A new disease of redcedar caused by *Cercospora sequoiae* has been noted in several forest nurseries. The distinguishing symptom of the disease is a gradual browning of the needles starting on the oldest needles on the lower branches and gradually spreading upward and outward. In advanced stages, only the tips of the seedlings remain green. This disease is easily distinguished from Phomopsis blight, which results in the death of the branch tip.

Although this disease has not been noted on Arizona cypress seedlings in the nursery, it is known to cause a serious needle blight disease of Arizona cypress in plantations. All cypress used as windbreaks around nurseries should be examined for this disease and all infected plants removed or sprayed. The most effective fungicide for use against this disease is Bordeaux mixture. Seedlings should be sprayed at 7 to 10-day intervals once the disease is determined to be present, or where it recurs frequently this spray schedule can be made standard practice, starting June 1.

Chlorosis

Chlorosis is a general term denoting a yellow color of the foliage. Two general types of chlorosis may be found in the nursery. The commonest type involves general pale yellowing of all the needles of the seedling; this type results from nitrogen deficiency. Application of ammonium nitrate or some other nitrogen source will usually correct this condition. The rate and number of applications will depend upon many diverse soil and other factors, but 25 to 50 pounds actual nitrogen per acre per application is usually sufficient.

Another type of chlorosis often seen in nurseries is characterized by a creamy-white color of the new needles, while the older needles retain a normal green color. In severe cases, however, some of the older needles may also become chlorotic. The most common cause of this type of chlorosis is iron deficiency. This does not necessarily imply a deficiency of iron in the soil. The problem is one of availability of iron to the plant. Many factors affect utilization of iron in the soil by the seedlings, one of the most important of which is soil pH. Most nurseries have small localized areas in which seedlings appear chlorotic every year. Such areas usually have a soil pH of 7 or above. Application of acid-forming fertilizers such as ammonium or ferrous sulfate will lower the pH.

Low soil pH (below 5.0) coupled with high phosphate content sometimes results in binding the iron in an insoluble iron-phosphate complex. Raising the pH with lime will often remedy this situation.

Where iron deficiency is a problem, the use of iron chelate is the fastest way to correct chlorosis. Application of 3 pounds actual iron per acre is usually sufficient. Where more iron is needed, it is best to make frequent applications rather than increasing the amount at any one application.

In addition to nitrogen and iron deficiency, chlorosis can be caused by hot weather, root diseases, chemical injury, or other factors.

Since it is often difficult to determine the exact cause of chlorosis, the control must be attempted on a trial-and-error basis.

Chlorotic seedlings are very sensitive to injury by mineral spirits. If chlorosis is widespread in the nursery, the rate of mineral spirits used for weed control should be decreased or the spraying terminated until the seedlings return to their normal color.

Sand Splash

Sand splash is caused by rain or irrigation water splashing soil on the needles and stems of seedlings. If the soil is high in silt or clay content, soil particles will adhere tightly to the seedling. Continued splashing may build up a coat of soil $\frac{1}{4}$ inch or more thick on the seedling; then the layer of sand can cut down photosynthetic area and reduce growth. The most damage, however, is caused by pathogenic fungi which are splashed up with the sand and kill needles or sometimes the entire seedling.

The best control for sand splash is an adequate mulch to reduce splashing. A soft rake or flap may be pulled over the beds to dislodge the sand.

Thelephora Terrestris

Thelephora terrestris is one of the most common fungi seen in the nursery. The small, purple, shelf-shaped or funnel-shaped fruiting bodies can be found attached to seedlings and debris or on the ground. Although the fungus often uses seedlings for support of the fruiting body, little if any damage is done to the seedling. There is no need to control the fungus.

Foliage Application of Fungicides

Control of diseases such as fusiform rust, Phomopsis blight, and brown spot in forest nurseries is done by periodic spraying with fungicides. Adequate control of these and other foliage diseases is dependent upon application of the correct fungicide in the correct amount at the correct time. All fungicides presently used in forest nurseries act only as protectants and not as eradicants. For this reason, it is imperative that the fungicide be applied to the foliage before the fungus has a chance to penetrate the plant tissue.

The foliage must be uniformly covered with the fungicides. To accomplish this, it is necessary to disperse the liquid into very small droplets. In most nurseries, this is accomplished by passing the liquid through small holes (1/32 inch or less in diameter) at a pressure of at least 300 pounds per square inch. Even finer droplet size can be obtained by the use of a mist blower and this has an added advantage in utilizing a smaller volume of water; hence, more beds can be sprayed at one passing. Both of these factors are important when attempting to cover the nursery in the shortest time possible.

Calibration and adjustment of the sprayer are also important in obtaining a uniform coverage. The spacing of the nozzles on the spray boom and the height of the nozzles above the seedlings are largely determined by the type of nozzles used. The spray stream from each nozzle should overlap slightly near the top of the seedlings. Since the amount of spray applied is dependent upon the orifice size of the nozzle, pressure, and speed of the tractor, it is important that the sprayer be carefully calibrated at the beginning of each season and then checked at periodic intervals. Seventy-five to 100 gallons of water per acre with a pressure sprayer, and 25 to 30 gallons per acre with a mist blower will give good coverage.

Because of the layer of waxy substances covering the surface of conifer needles, and to a lesser degree hardwood leaves, spray droplets do not flatten out to give complete coverage when they fall on the plant. To remedy this, materials may be added to the spray solution in order to lower the surface tension and allow the spray droplets to flatten. These surfactants or "spreaders" are usually combined with "stickers" which cause the fungicide to adhere to the foliage and thus resist removal by rain or irrigation water. Some fungicide mixtures contain spreader-stickers when they are purchased; most do not, however. Several good spreader-stickers are on the market. These should be added to the spray solution as it is mixed.

The number and frequency of applications are dependent upon the disease being controlled, weather conditions, and rate of growth of the seedlings. Except under conditions of high rainfall, most fungicides will remain effective on the foliage for 10 to 14 days. During periods of rapid growth, the interval between successive applications should be shortened in order to provide coverage of unprotected new growth. During such periods, sprays should be applied at 5 to 7 day intervals.

A knowledge of the disease is very important in determining when and how often to spray. Sprays to control fusiform rust must be applied from the time the seedling emerges to about July 1, when weather conditions are unfavorable for further infection. Phomopsis blight, on the other hand, does not appear until about June but may be active until October. In general, foliage diseases require periods of high humidity for optimum spread and infection. Because of this, it is wise to make an extra spray application immediately following a wet period. If the forecast is for several days of wet weather, it is better to make the application beforehand.

Drenches

Drenching is the application of chemicals to the soil with the use of large amounts of water. For the most part, drenches are used around living plants. They are aimed primarily at preventing enlargement or intensification of an existing infection, and not eradication of a disease.

Unlike the soil fumigants, which move through the soil mostly as gas, chemicals used for drenches usually have a low volatility. For this reason, enough water must be added following application to move the chemical down into the root zone. For small areas the chemical can be put on with a hand sprayer or a sprinkling can. The remainder of the water can be added through the irrigation system. About 3/4 inch of water will distribute the chemical through the upper 6 inches of soil. For large areas, the material can be applied with a power sprayer or through the irrigation system. Drenching of large areas is often prohibitive in cost.

Drenching is at best only a temporary control. Most chemicals used for drenching are rapidly inactivated in the soil or may be leached out. For persistent trouble spots involving soil organisms, an eradicant treatment with an all-purpose soil fumigant should be used.

Soil Fumigation

Soil fumigation is a process in which a volatile organic chemical is introduced into the soil with the subsequent release of toxic vapors. Some of these chemicals can be classified as all-purpose soil fumigants and will effectively control all groups of soil microorganisms as well as weeds. Others are more specific and will control only nematodes. There are no fumigants that are specific for fungi alone. The success of soil fumigation depends largely upon the following soil conditions:

1. Soil temperature. Soil fumigants are most effective at temperatures between 50° and 80° F. In general, the lower the temperature, the longer it takes to get complete fumigation and for the fumigant to escape from the soil after the fumigation period is over.

2. Soil moisture. The optimum soil moisture level for most effective fumigation is at or near field capacity, which approximates the optimum moisture level for planting. High moisture levels result in a poor job of fumigation and a slow escape of the fumigant from the soil.

3. Soil tilth. Since most fumigants move through the soil in the gaseous state, it is important that the soil be in good tilth. Disking or plowing to 6 or 8 inches should be done immediately before fumigation. Plowing following completion of the fumigation period will aid in the escape of the fumigant from the soil.

4. Soil texture and organic matter. Most recommendations for soil fumigants are based on light-textured soil with relatively little organic matter. On heavy soils, or those with a high organic matter content, the rate of application should be increased by 25 to 50 percent. The waiting period before planting should also be increased. Cover crops should be turned under at least 2 months before fumigation.

In addition to the increased growth of seedlings attributable to the control of disease organisms and weeds, general soil fumigants appear to stimulate the growth of seedlings. In soils of high fertility, the stimulation sometimes results in seedlings that grow too large. When this happens, some modification should be made in the fertilization or irrigation program.

Some of the more specific properties and techniques of application of the more commonly used soil fumigants are given below.

Methyl bromide is usually sold as a mixture containing 98 percent methyl bromide and 2 percent chloropicrin, the latter acting as a tear-gas warning for the presence of the odorless methyl bromide. It is available in the commonly used 1-pound cans or large cylinders.

The standard procedure for the use of this chemical is to release it beneath a gasproof cover, usually a 4-mil thick polyethylene sheet approximately 100 x 20 feet in size. The cover is supported on sacks of straw, the edges are sealed with soil, and the methyl bromide released by means of special applicators.

Another technique for application of methyl bromide is the injection of a mixture of methyl bromide and a solvent such as Varsol 6 to 8 inches into the soil by the use of a special apparatus. The treated area is then covered with a polyethylene cover. The major advantages of this method are that larger covers can be used and no support is needed since more efficient utilization is obtained by injection. On most soils, 250 pounds per acre actual methyl bromide is sufficient.

A third method for the application of methyl bromide involves the use of a special device which lays the polyethylene cover and seals the edges. Methyl bromide, vaporized by passage through a hot-water bath, is released through two hoses trailing beneath the cover. At present, only relatively narrow covers (6 to 8 feet) can be used with this method. Since the complete treatment of an area with this machine would require considerable overlapping of treated area, its use in forest nurseries would probably be limited to treatment of individual beds.

Regardless of the fumigation method used, the covers can be removed 24 to 48 hours after treatment, depending upon the soil type and temperature. Planting can be done 48 hours after the cover is removed.

The cost of methyl bromide fumigation depends upon application method used, the amount of fumigant, size of area, and proficiency of the fumigation crew. In general, the cost averages $350 to $500 per acre. Compared to the total value of the seedlings produced, this is a small price to pay for the insurance of producing a quality crop of seedlings. At $400 per acre, an average increase of only $3\frac{1}{2}$ seedlings per square foot will completely pay for the cost of fumigation in one season. There is good evidence, however, that fumigation will give good control of root diseases for 3 to 4 years, thus bringing the cost per year down to approximately $100 per acre. Fumigation also gives good weed control for one or more years.

Vapam or VPM has been widely used as an experimental general soil fumigant in forest nurseries, but only with little success because of ineffective methods of application. This material has been applied in several ways, most of which involve injecting the material into the soil or putting it through the irrigation system. The surface of the soil is packed with a heavy roller or irrigated with about 3/4 inch of water in an attempt to form a seal to prevent the escape of the gas. Recent work has shown that injection of the material into the soil at the rate of 50 gallons per acre (one-half the rate usually recommended for Vapam) and covering with a polyethylene cover for 48 hours gave consistent results comparable to methyl bromide. The total cost of this operation is about the same or less than methyl bromide. The major disadvantage is that planting cannot be done for 2 weeks after the cover is removed. The soil should be disked at least once before planting to facilitate escape of the chemical from the soil after removal of covers.

Mylone is another general soil fumigant that has been widely tested in forest nurseries. It is available as an 85 percent wettable powder that can be applied to the soil surface with a sprayer or as a dry powder which can be applied with a fertilizer spreader. The usual rate of application is 200 to 300 pounds per acre. After application, it is disked or rototilled to a depth of 6 to 8 inches. No cover or seal is required. A 2 to 3-week waiting period is required before planting. It is comparable in cost to methyl bromide, but has not so far given consistently good results.

Ethylene Dibromide (EDB) at recommended dosages is effective only against nematodes, and has no effect on fungi or weed seeds. It is injected into the soil at the rate of 10 to 15 gallons per acre of the 85 percent material. No surface seal is necessary. A waiting period of at least 2 weeks is necessary before planting.

Dichloropropane-dichloropropene mixture (DD) is injected into the soil in the same manner as EDB. At the recommended rate of 20 to 25 gallons per acre, it is effective only against nematodes. Rates of 100 gallons or more per acre have been reported to give weed control and possibly control of root disease fungi. A waiting period of 2 to 3 weeks is necessary before planting.

DBCP is available in both the granular or liquid form. The liquid form is applied in much the same way as EDB and DD. The granular form is spread with a fertilizer distributor and disked in. No surface seal is necessary. A waiting period of 2 to 3 weeks is necessary before planting. The recommended dosage is 20 to 35 pounds active ingredient per acre.

Like DD and EDB, DBCP is effective only against nematodes. It has one additional advantage over EDB and DD in that it can be used as a drench on living seedlings. Application of this material through the irrigation system has proven very effective. Four gallons of the active ingredient is mixed with about 100 gallons of water and injected into the irrigation system. An additional $\frac{1}{2}$ to $\frac{3}{4}$ inch of water is then used to distribute the chemical in the root zone. The undiluted material is highly toxic to seedlings and should never be used.

Other fumigants could be mentioned in connection with disease control, but they are not discussed because they have been inadequately tested in southern forest nurseries, or are not readily available, or have some marked disadvantages.

Chemical	Manufacturer	Formulation	Rate per acre [1]	Method of application	Disease controlled
Bordeaux mixture		8-8-100	100 gal.	Spray	Brown spot, Cercospora blight
Captan				Drench	Damping-off
Captan 50-W	Stauffer	[2] 50% WP	4 lbs.		
Orthocide 50	Cal. Spray	50% WP	4 lbs.		
DBCP				Preplant fumigation	Nematodes
Fumazone	Dow	70% E	2 gal.		
Nemagon	Shell	50% E	2 gal.		
		10% G	175 lbs.		
		30% G	60 lbs.		
Fumazone		70% E	4 gal.	Post-plant drench	Nematodes
Nemagon		50% E	4 gal.		
Ethylene dibromide				Preplant fumigation	Nematodes
Dowfume W-40	Dow	40% S	22 gal.		
Dowfume W-85	Dow	75% S	10 gal.		
Soilfume 40	Niagara	40% S	22 gal.		
Soilfume 85	Niagara	85% S	10 gal.		
Ferbam				Spray	Fusiform rust, Cylindrocladium blight
Fermate	DuPont	76% WP	2 lbs.		
Ferradow	Dow	76% WP	2 lbs.		
NuLeaf	Cal. Spray	76% WP	2 lbs.		
Karbam Black	Sherwin-Williams	76% WP	2 lbs.		
Iron chelate				Spray	Iron chlorosis
Sequestrene 138 Fe	Geigy	6% WP	50 lbs.		
Sequestrene Na Fe	Geigy	12% WP	25 lbs.		
Versonol	Dow	9% WP	37 lbs.		
Methyl bromide				Preplant fumigation	Soil-borne diseases in general
MC 2	Dow	98% VL	300-400 lbs.		
Bedfume	Niagara	98% VL	300-400 lbs.		
Pestmaster	Michigan	98% VL	300-400 lbs.		
Methyl bromide	Kolker	98% VL	300-400 lbs.		
Brozone	Dow	70% in solvent	250-300 lbs. (actual methyl bromide)		
Merbam	Berk	10% WP	1½ lbs.	Spray	Phomopsis blight
Mylone	Union Carbide	85% WP	300 lbs.	Preplant fumigation	Soil-borne diseases in general
Puritized Agricultural Spray	Gallowhur	3% S	1 pt.	Spray	Phomopsis blight
Spreader-stickers			Use according to manufacturer's directions		
DuPont Spreader-Sticker	DuPont				
Ortho Spray Sticker	Cal. Spray				
Santomerse S	Monsanto				
Triton B 1956	Rohm & Haas				
PCNB				Spray	Damping-off, Rhizoctonia blight
Terrachlor	Olin Mathieson	75% WP	50 lbs.		
Thiram				Drench	Damping-off
Arasan 75	DuPont	75% WP	40 lbs.		
Tersan 75	DuPont	75% WP	40 lbs.		
Thiram 75W	U. S. Rubber	75% WP	40 lbs.		
Vapam				Preplant fumigation	Soil-borne diseases in general
Vapam	Stauffer	Liquid	50 gal.		
VPM	DuPont	Liquid	50 gal.		

1/ Based on chemicals as purchased.
2/ E = emulsion, WP = wettable powder, S = solution, G = granular, VL = volatile liquid.

ADDRESSES OF MANUFACTURERS OF CHEMICALS

F. W. Berk Company, Woodridge, New Jersey

California Spray-Chemical Corporation, Richmond, California

E. I. duPont de Nemours Company, Inc., Grasselli Chemicals Division, Wilmington, Delaware

Dow Chemical Corporation, Midland, Michigan

Gallowhur Chemical Corporation, North Water Street, Ossining, New York

Kolker Chemical Corporation, 600 Doremus Avenue, Newark 5, New Jersey

Olin Mathieson Chemical Corporation, Insecticide Sales Division, Baltimore 3, Maryland

Michigan Chemical Corporation, 500 North Bankston, St. Louis, Michigan

Monsanto Chemical Company, 710 N. 12th Boulevard, St. Louis, Missouri

Morton Chemical Company, Panogen Division, Woodstock, Illinois

Niagara Chemical Division, Food Machinery-Chemical Corporation, 100 Niagara Street, Middleport, New York

Rohm and Haas Company, 222 W. Washington Square, Philadelphia 5, Penna.

Shell Chemical Corporation, Agr. Chemical Division, 460 Park Avenue, New York 22, New York

Sherwin-Williams Company, 113 Guild Hall Building, Cleveland 1, Ohio

Stauffer Chemical Company, 380 Madison Avenue, New York 17, New York

Union Carbide Chemicals Company, 30 East 42nd Street, New York 17, New York

U. S. Rubber Company, Naugatuck Chemical Division, Naugatuck, Connecticut

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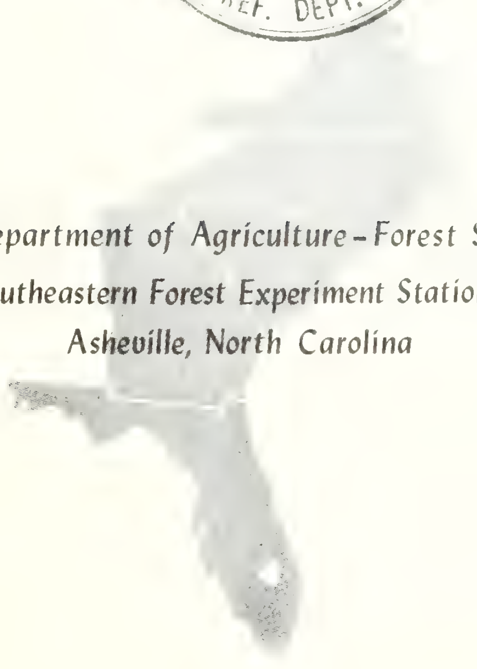
Variance of Nuclear Moisture Measurements

by

James E. Douglass



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Variance of Nuclear Moisture Measurements

by

James E. Douglass

The neutron method, a rapid, precise way of measuring soil moisture in situ, has become widely used in soil research in recent years. Theoretical aspects of the method are well known, but data concerning the error of field moisture measurements and experimental designs which control error are meager. In studies concerning moisture storage, drainage, and evapotranspiration, data are often averaged for an area of land. An important step in planning this sort of study is selection of an experimental design which controls error so that it does not exceed the allowable limit. To do this, one must know something about sources of moisture variation and their magnitude.

Some experience with the error of field measurements (total error arising from all sources) and instrumental sources of error has accumulated. Jarrett (3) discussed theoretical aspects of the error of radiocounting and others (4, 5) have used his work as a basis for estimating the random counting error of individual measurements. This error is usually insignificant if several measurements are made within a soil stratum and particularly when compared with error arising from the variation in moisture from point to point in the soil. The only reported comparison of field measurement errors of the neutron and other methods was by Stone et al. (7). They found that for the soil studied one neutron sample gave information equal to seven gravimetric samples. Such information is valuable but does not give the experimenter the information needed for designing a study using the neutron method.

Information pertaining to sources of variation, methods of reducing variance, and designs which capitalize on advantages of the method can be best determined by prestudy sampling of the moisture population. This paper presents results of such a sampling study. Quantitatively the results apply only to the soil studied, but some observed relationships are applicable in principle to other soils and areas and may aid those contemplating use of nuclear equipment.

METHODS

A 19-year-old loblolly pine plantation growing on a nearly level old field in the South Carolina Piedmont was selected for the study. The soil series is Cataula and is characterized by a sandy Ap layer underlain by a clay B horizon. The area appeared to be homogeneous with respect to slope, aspect, topographic position, depth and texture of the Ap layer, soil series, and timber stand characteristics.

Within the plantation, two blocks approximately $\frac{1}{4}$ acre in size were established. Each block was stratified into two plots, and within each plot two randomly located sampling positions were established. At each position two access tubes (subsamples) were installed 36 inches apart and to a depth of 8 feet. The soil from each 1-foot depth was saved for laboratory analyses of texture, wilting point, and moisture equivalent. Moisture content was measured weekly at 1-foot depth intervals (fig. 1) and expressed as inches per foot of soil.

Analysis of variance techniques were used to determine significant differences in the sources of variation. More importantly, the design was used to compute the individual components of variance (6). Components of total variance (identical with sources of variation in the analysis of variance table) were as follows: between blocks; between plots within blocks; between positions within plots; and between determinations at the same position. The value obtained for each component was separate from and unaffected by variation due to all other components. Thus, the greatest contributor(s) to total variance were easily identifiable.

Figure 1.--Moisture content was determined with the Nuclear-Chicago Corporation P-19 Moisture Probe and Model 2800 Scaler. Spacing and relative size of the stand is shown in background.

RESULTS AND DISCUSSION

Total Moisture Content

The moisture content at the same depth varied greatly between sampling points on any one day. For example, the variation in moisture content of the surface foot of soil on one particular day ranged from 2.89 to 5.99 inches. The range of moisture contents encountered at lower depths was also large.

Estimated values of the various variance components are presented in table 1. Each value is the average of 6 independent estimates obtained during a 1-month moisture-depletion period.

In the surface foot, positions within plots were significantly different in moisture content, and this was the chief component of variation. Positions were also significantly different in the 4 to 5 and 0 to 4-foot depths.

The plots-within-blocks component contributed little to variance of moisture in the surface 6 feet of soil. However, in the 6 to 7 and 7 to 8-foot depths, plots within blocks was a major component of variation and the plots held significantly different volumes of moisture.

Below one foot, the block component was the largest contributor to moisture variance, and blocks were significantly different in the 3 to 4, 4 to 5, 5 to 6, 0 to 4, and 0 to 8-foot depths.

The contribution of dual determinations at the same position (2 samples 36 inches apart) varied with depth, normally being small for individual depths and large when summed for several depths. The standard error varied from 0.05 inch for the 6 to 7 and 7 to 8-foot depths to about 0.30 inch for the 0 to 8-foot profile.

Variation of this order could conceivably mask relatively important treatment differences. One naturally speculates about the cause of such large variation between blocks, plots, and positions on an apparently homogeneous site. Vegetation differences were examined but failed to account for the variation. Clay content at each sampling point was next examined because it is generally recognized that texture is correlated with moisture content on a weight or volume basis (1, 2).

Figure 2 illustrates the relationship between total moisture and clay content of all depths and sampling points at one point in time. For each 10 percent increase in clay content, moisture volume increases by about one inch per foot of soil. The correlation is surprisingly strong ($r = .88$) when differences in moisture tension and soil density from place to place within the soil are considered.

Table 1.--Components of variance in total inches of water by soil depths [1]

Component of variation	Soil depth in feet									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	0-4	0-8
	Components of variance in total inches of water									
Between blocks	0.2210	0.1282	0.2330	0.9500*	1.3796*	1.7301*	1.2223	0.4628	5.8665*	47.4554*
Between plots within blocks	-	-		.0346	-	.0692	.1990**	.1898**	-	1.0832
Between positions within plots	1.0103**	.0680	.0465	.0934	.3320**	.0250	-	-	1.1585*	.8680
Between determinations at the same position	.2784	.0576	.0640	.0736	.0976	.1104	.0304	.0480	.7888	1.4560

1/ Dash indicates that the best estimate of the component is 0.
* Significantly different from 0 at the .05 level as determined from analysis of variance table.
** Significantly different from 0 at the .01 level as determined from analysis of variance table.

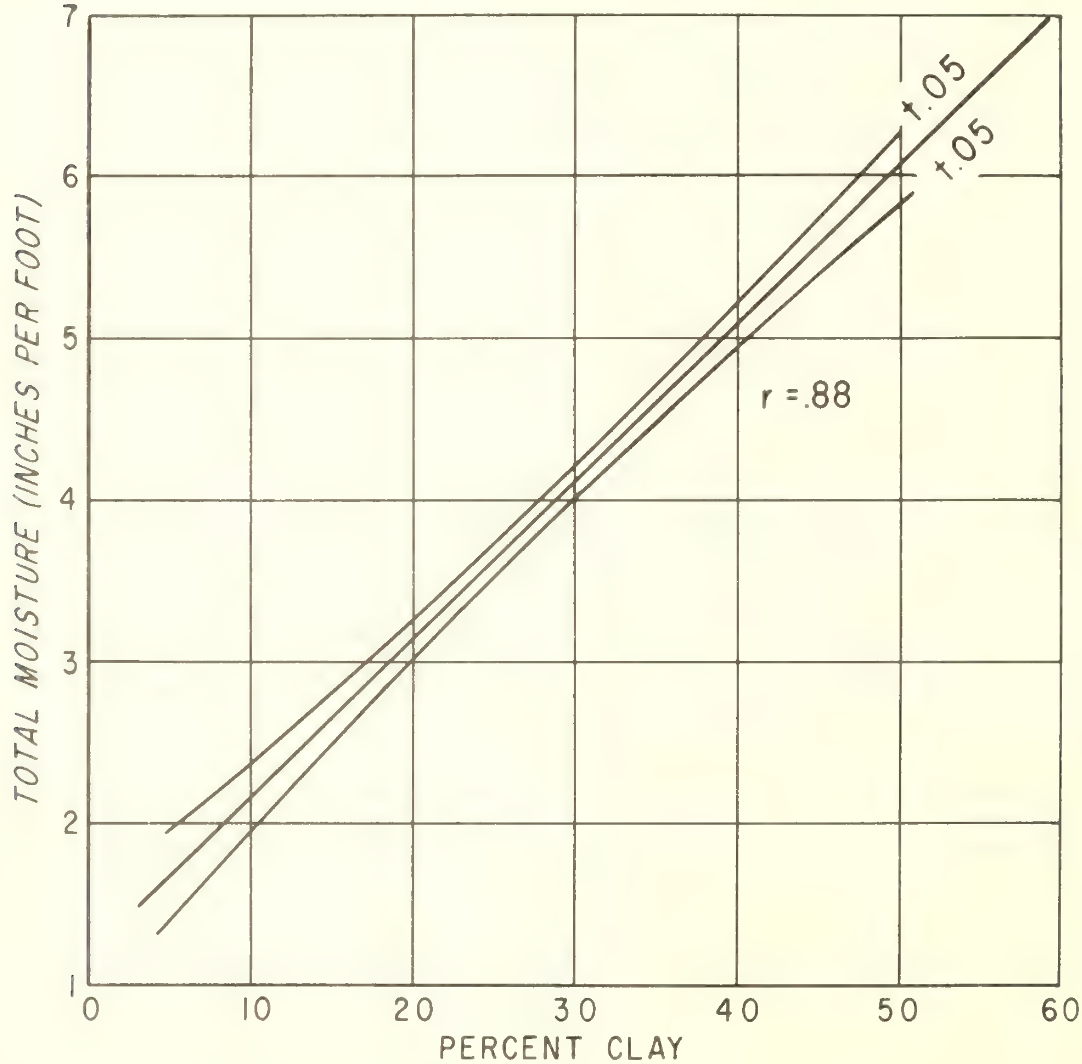

Figure 2.--Relationship of total water to clay content.

Using the same statistical model as in the analysis of total moisture content, the components of variation in clay content were estimated (table 2). Comparison with table 1 reveals that where clay content differs significantly, total moisture is also generally significantly different. Thus, clay content appears to be responsible for much of the variation in moisture volumes.

Table 2.--Components of variance in percent clay content by soil depths[1/]

Component of variation	Depth in feet							
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
	Components of variance in clay content							
Between blocks	42.70	40.19**	66.81	247.58**	155.88**	166.63*	128.32	50.50
Between plots within blocks	-	-	-	-	2.12	17.50	7.50	21.00
Between positions within plots	49.25*	-	46.75	-	-	-	11.25	15.00
Between determination at the same position	9.06	22.50	28.75	36.75	55.55	24.75	10.00	11.00

1/ Dash indicates that the best estimate of the component is 0.
* Significantly different from 0 at the .05 level as determined from analysis of variance table.
** Significantly different from 0 at the .01 level as determined from analysis of variance table.

These data are strong empirical evidence that where clay content is homogeneous, moisture variance will be small; and, conversely, if it is variable, moisture variance will be large. To illustrate this, data were grouped by clay content classes (assuming random sampling) and the standard error of moisture volume was calculated. Figure 3 illustrates graphically the theoretical consequences of an increasing range in clay content on the number of samples required for given standard errors. If the range in clay content increases from $\pm$ 5 percent to $\pm$ 10 percent, about twice as many samples are required to obtain a given error.

The study findings suggest that experimental error will be large for this series if total moisture volume is used to compare treatment responses. The interdependence of clay content and moisture volume precludes use of the latter as a valid indicator of soil moisture stress, unless the effect of textural differences can be removed through a covariance analysis. It is entirely possible for two soils to be at wilting, yet one contain a volume of moisture twice as great as the other simply because of differences in clay content.

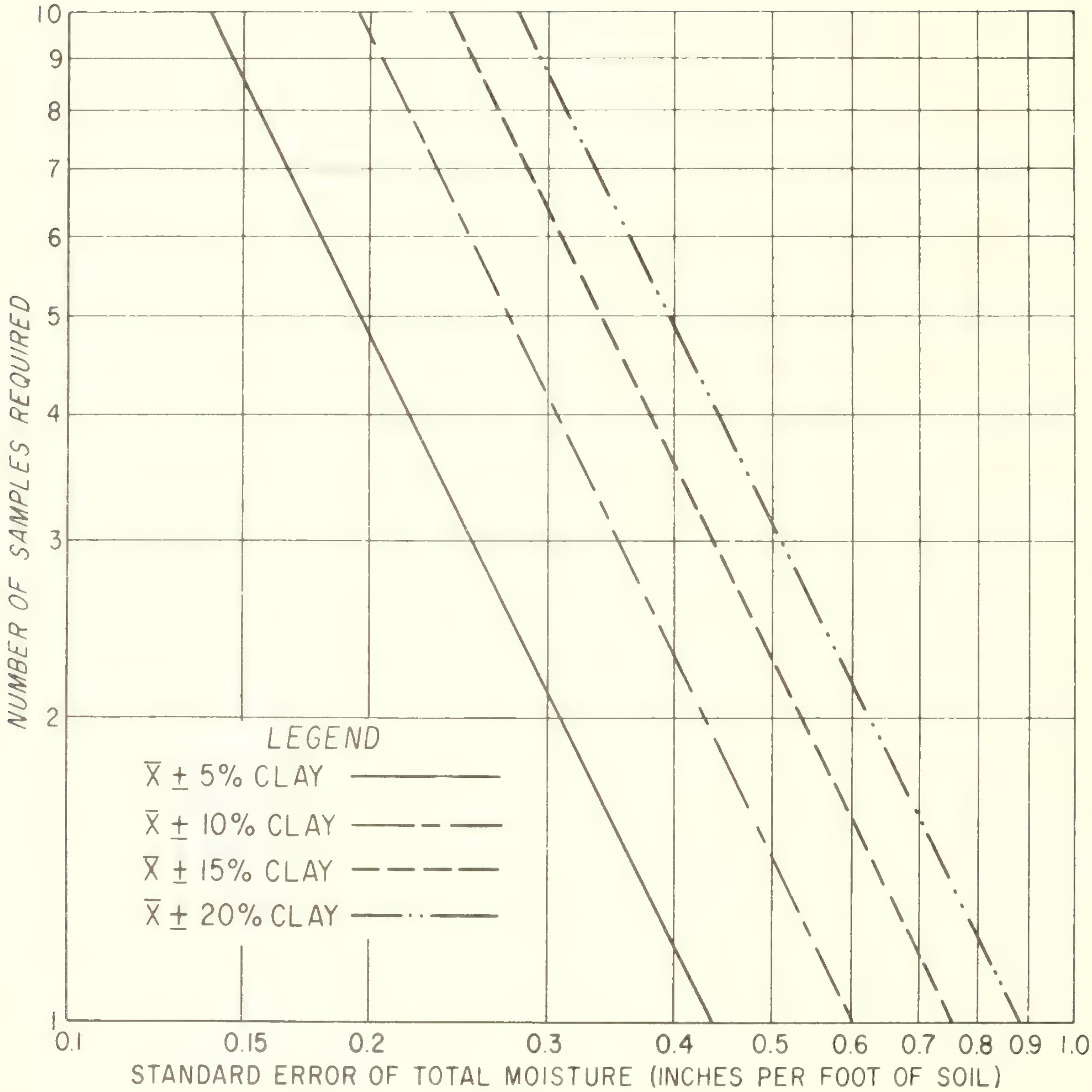

Figure 3.--Number of samples needed, for several ranges in clay content, to achieve certain standard errors of total moisture.

Moisture Losses

An analysis of moisture losses or change in moisture content with time has distinct advantages over a comparison of total moisture content. Biologically, losses are more meaningful than total moisture. Considering the usual study objectives in hydrology, the quantity required is generally moisture loss (which may be termed change in moisture content, moisture deficits, change in storage, etc., as serves the descriptive needs of the individual).

Since the same soil mass can be remeasured, losses can be determined for each sampling point. Analysis of individual losses automatically includes covariance and reduces experimental error. Also, losses, since they are numerically less than total moisture content, give a smaller error in terms of moisture volume or inches per foot of soil if the coefficients of variation of the two are about the same.

Moisture losses were computed for the same depletion period used in the analysis of total moisture, and the contribution of each component to total variance in moisture loss was determined (table 3). Note that the only significant difference is in the 3- to 4-foot depth. This analysis, in terms of water loss, eliminated most of the variation observed when total moisture content was the basis for comparison (see tables 1 and 3).

A word of caution is needed at this point. The greatly reduced variation and near absence of significant differences between components does not mean that texture is unimportant when losses are being compared. Clay content is also related to moisture loss. The relationship is negative, strong in the surface foot (r = .87), but considerably less in lower horizons. The effects of textural variations disappear when losses from individual depths are summed, as in obtaining total loss from the 0- to 4-foot depth. Therefore, prospective experimental areas should be examined for homogeneity of soil texture, particularly if individual depths are to be compared.

Table 3.--Components of variance in soil moisture loss by soil depths[1/]

Component of variation	Depth in feet									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	0-4	0-8
	Components of variance in soil moisture loss									
Between blocks	0.0659	-	0.0108	0.1285*	-	0.0005	0.0001	-	0.0209	-
Between plots within blocks	.0015	-	.0190	-	0.0047	.0004	-	0.0002	.0342	0.1041
Between positions within plots	.0282	-	-	.0091	-	-	-	-	.0902	.0853
Between determinations at the same position	.0413	0.0521	.0797	.0346	.0286	.0032	.0039	.0024	.2874	.2826

1/ Dash indicates that the best estimate of variance is 0.

* Significantly different from 0 at the .05 level as determined from the analysis of variance table.

The number of samples required for an analysis of losses and total moisture is illustrated in figure 4. For a given precision level, an analysis by losses requires about one-tenth as many samples as a total moisture analysis. Again, these are theoretical values based on random sampling.

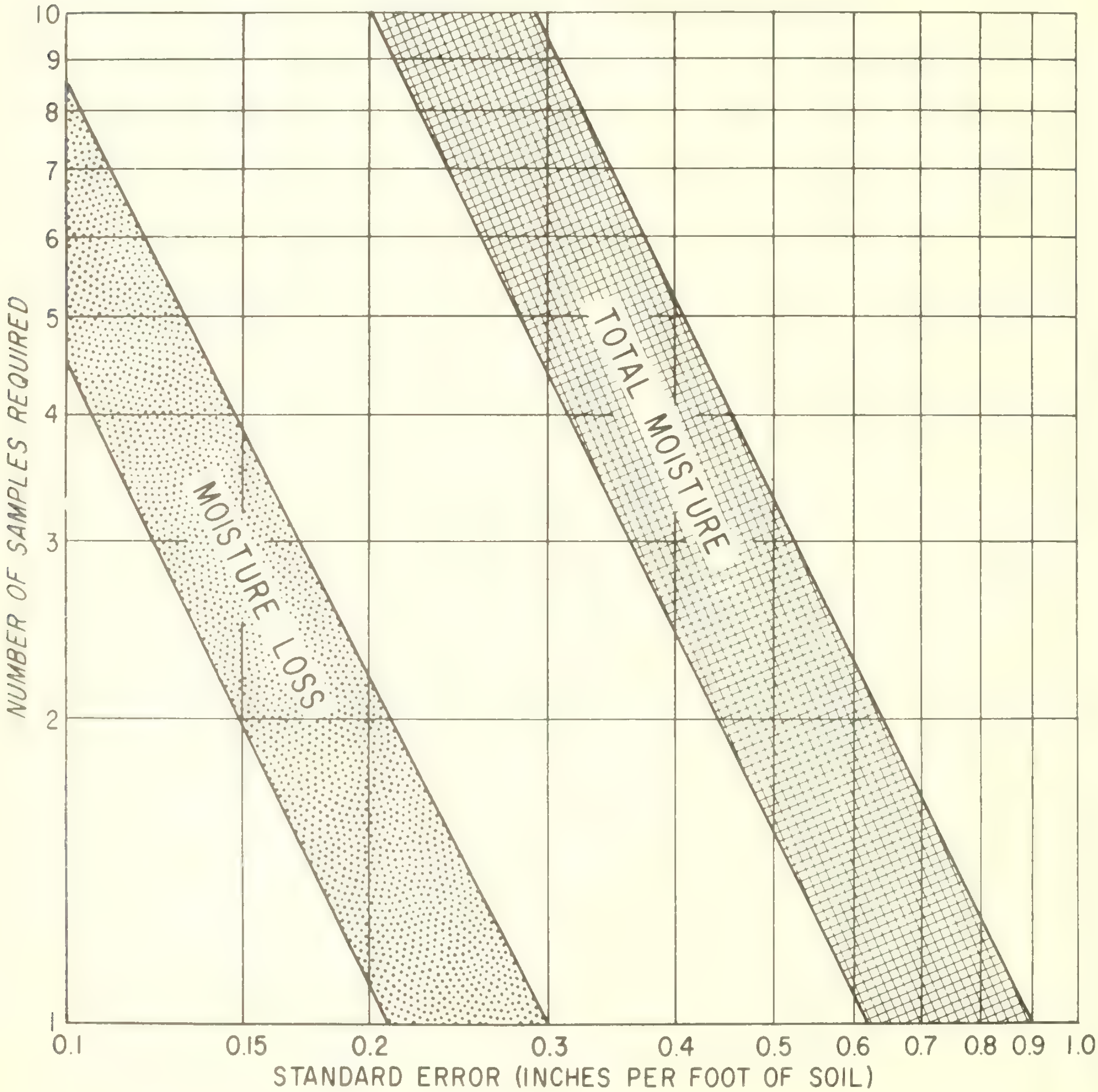

Figure 4.--Number of samples required to hold the standard error of total moisture and moisture loss to specific amounts. Upper and lower limits represent ranges in clay content of 40 and 20 percent, respectively. The curve is valid only to a depth of 5 feet.

Design Efficiency

One naturally wonders whether the design used could be improved. All evidence suggests losses as the most precise method of comparing moisture conditions and it, rather than total moisture, will be considered.

In the design, each block was divided into two strata (plots). Subsampling within strata provided a means of determining the contribution of these components to total variance--an unknown prior to the study. Within plots, only determinations at the same position made an appreciable contribution to total variance (table 3), and a more precise measure of loss would have been obtained if the four samples had been randomized within plots. The following tabulation shows the estimated gain in precision which would result from randomly sampling within plots.

Soil depth (Feet)	Precision gain (Percent)
0-1	40
1-2	0
2-3	0
3-4	21
4-5	0
5-6	0
6-7	0
7-8	0
0-4	24
0-8	23

The plots-within-blocks component contributed little to total variance, and stratifying blocks into plots decreased rather than increased precision. The between-blocks component contributed appreciably to variance in only two depths (table 3). Thus, it can be concluded that, in general, more information would be obtained by random sampling of the population.

If the population is sampled at random, how many samples are needed? This can be determined directly from figure 4 if variability of clay content of the soil and desired error are known.

Applicability of the data in figure 4 to other soils and areas is not known. However, since data are for soils of variable texture and density within depths, they may have application to soils of similar characteristics and should be conservative for more homogeneous soils. Until better data are available, figure 4 affords a useful guide in planning future studies.

SUMMARY

Results from this study lead to several tentative conclusions concerning use of the nuclear equipment to measure moisture in Piedmont soils.

1. The error of total moisture content determined by the neutron method is large, particularly where soils vary considerably in texture. Consequently, it is difficult to detect differences between treatment means unless covariance techniques are used to remove textural effect.

2. Analysis of moisture losses is, for several reasons, a more precise analysis for detecting treatment differences than total moisture content. For the same experimental precision an analysis by losses requires fewer samples than a total moisture content analysis.

3. The error of both total moisture content and moisture loss increases as the range of clay contents encountered increases.

4. For the area involved, random sampling of the moisture population would have been the best possible design for sampling moisture in the study area.

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lorest Fuels on Organic and Associated Soils in the Coastal Plain of North Carolina

by

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Local, accepted common, and scientific names of the principal species of vegetation in organic and associated soil fuel types

LOCAL	ACCEPTED COMMON NAME	SCIENTIFIC NAME
	Blackberry	Rubus sp.
	Common Sweetleaf	Symplocos tinctoria (L.) L'Her.
	Loblolly-Bay	Gordonia lasianthus (L.) Ellis
	Leatherleaf	Chamaedaphne calyculata
Swamp Maple	Red Maple	Acer rubrum L.
	American Holly	Ilex opaca Ait.
Sweet Pepperbush	Summersweet Clethra	Clethra alnifolia
Winged Sumac	Shining Sumac	Rhus copallina L.
	Smooth Sumac	Rhus glabra L.
Myrtle Dahoon	Dahoon	Ilex cassine L.
Tall Gallberry	Large Gallberry	Ilex coriacea (Pursh) Chapm.
Common Gallberry	Inkberry	Ilex glabra
Wild Raisin	Witherod Viburnum	Viburnum cassinoides
	Swamp Cyrilla	Cyrilla racemiflora L.
	Dangleberry	Gaylussacia frondosa
Sheep Laurel	Lambkill	Kalmia angustifolia
	Fetterbush	Lyonia lucida
	Pinxterbloom Azalea	Rhododendron nudiflorum
Trailing Blueberry	Creeping Blueberry	Vaccinium crassifolium
Honeycup	Dusty Zenobia	Zenobia pulverulenta
	Redbay	Persea borbonia (L.) Spreng.
Greenbrier	Laurel Greenbrier	Smilax laurifolia
Greenbrier	Common Greenbrier	Smilax rotundifolia
	Carolina Jessamine	Gelsemium sempervirens
White Bay	Sweetbay	Magnolia virginiana L.
Myrtle	Southern Bayberry	Myrica cerifera L.
Blackgum	Black Tupelo	Nyssa sylvatica Marsh.
	Sweetgum	Liquidambar styraciflua L.
	Chokeberry	Aronia arbutifolia
Reed	Switch Cane	Arundinaria tecta (Walt.) Muhl.
	Bracken Fern	Pteridium aquilinum
	Pond Pine	Pinus serotina Michx.
	Loblolly Pine	Pinus taeda L.
	Longleaf Pine	Pinus palustris Mill.
Wire Grass	Pineland Three-awn	Aristida stricta Michx.
	Bluestem Grasses	Andropogon spp.
	Beakrushes	Rhynchospora spp.
	Panicums	Panicum spp.
	Honeysuckle	Lonicera spp.

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Forest Fuels on Organic and Associated Soils in the Coastal Plain of North Carolina

by

G. W. Wendel, T. G. Storey, and G. M. Byram

INTRODUCTION

The fire problem in the organic soil (pocosin) areas of eastern North Carolina centers around the frequent and costly blowup[1/] wildfires occurring there and the use of fire as a management tool. Under certain combinations of fuel and weather, low intensity fires will suddenly and often unexpectedly multiply their rate of energy output many times. In almost all instances these fires have been virtually uncontrollable until the weather has moderated or the fire has run out of fuel. Efforts at control are often greatly hampered by inaccessibility and the poor soil trafficability in much of the area.

Prescribed fire appears to be a potentially valuable tool in the management of pond pine by promoting seed fall from the serotinous cones and in preparing the seedbed. Fires of sufficient intensity to achieve these results, however, are usually difficult to control and tend to burn deeply into the organic soil. The problem has become more acute in the past 10 years because of the increased commercial importance of the pocosins as pulpwood and timber producing areas. A better understanding of the behavior of fires in the pocosins, especially of the factors that favor the occurrence of major fires, could contribute much to the economy of this particular region as well as to the general fund of basic fire behavior knowledge.

1/ "Sudden increase in fire intensity or rate of spread sufficient to preclude direct control or to upset existing control plans. Often accompanied by violent convection and may have other characteristics of fire storm" (17).

Fuels and Extreme Fire Behavior

One of the most important factors contributing to the blowup fire potential is the quantity of live and dead understory and overstory fuel that constitutes a fire's basic source of energy. An additional source of energy of fires in the pocosins is the flammable organic soil.

During periods of drought, soils of high organic matter content have been consumed to depths of 2 or 3 feet. In very high intensity fires practically all of the brush and litter as well as the overstory foliage and light branchwood can be consumed. Usually there is spotting for considerable distances ahead of the main fire front. In order to provide presuppression measures to reduce the probability of blowup fires, better ways for recognizing the potential for extreme fire behavior are required. A system for rating fuels in terms of fire behavior would be an important first step in accomplishing this objective. Although eastern North Carolina is used as the study area, it should be pointed out that the main concepts in this paper are of a basic nature and should apply anywhere.

Previous Fuel Classifications

The literature contains several fuel classification systems. Fire researchers generally agree that fuel size, quantity, arrangement, and moisture content are the most important fuel variables that determine rate of fire spread and resistance to control (5, 6, 7). As a result, many of the present classifications, although mainly based on cover types, incorporate these variables and rate the cover types as to their relative rate of fire spread and resistance to control (8, 9). Much of the past work included some actual measurements, particularly of rate of spread and fuel weights (1), but most of the results are expressed only qualitatively. Only limited work has been done on the quantitative fire behavior significance of factors such as fuel energy content and rate of energy release.

Fire control people in eastern North Carolina recognize four general fuel types on organic soils; i.e., low pocosin, high pocosin, open cane, and overstoried cane, but no detailed descriptions have been written for these types. A more detailed fuel classification based on species composition, density, height, and age of rough[2/] would have more utility than the broad classification now in use. Because of the frequency and unpredictable behavior of large pocosin fires in the past, a classification based on the fuel-fire behavior relationships embodied in this paper will be even more useful.

2/ Years since last disturbance.

DESCRIPTION OF STUDY AND RESULTS

The objectives of the study were: (1) to type pocosin fuels based on species composition, height, and density; and (2) to determine the total weight per unit area of each of the types including vegetation and litter, group them into total weight classes, and rate each class for extreme fire behavior in terms of its blowup potential.[3]

In general, pocosins may be described as those areas, including swamps and bays, with soils having 20 percent or more organic matter content, fair to poor internal drainage, and supporting stands of pond pine (19). Also, these areas have a medium to heavy density understory composed principally of woody shrubs and reeds. The pocosins constitute roughly 2 million acres in coastal North Carolina, principally in the Dare-Tyrrell-Hyde County area in the northeast part of the State and in the several counties surrounding New Bern in the central coastal plain. Other isolated pocosins are found in the vicinity of Wilmington and Elizabeth City, North Carolina (fig. 1). Individual pocosins range from a few thousand acres in size to many thousands of acres and, until recently, were not very accessible. Large-scale drainage and development programs on many pocosins have hastened the drying of soils and made the area more accessible, but have increased the fire hazard.

General Fuel Types Selected

A preliminary reconnaissance of the various pocosins indicated that most of the fuel types, as well as the different organic soils, in the North Carolina coastal plain were represented on or in the vicinity of Hofmann Forest in Jones and Onslow Counties, North Carolina. As a result, the bulk of the sampling was done on Hofmann Forest. Other types which did not occur there were sampled on industry lands in Tyrrell County, and on the Croatan National Forest.

An extensive reconnaissance of Hofmann Forest was made and areas similar in species composition, apparent density, and height were identified as distinct fuel types. The pine overstory, if present, was not considered in identifying fuel types, although most types appeared to have a characteristic overstory. In all, 14 types were identified, described, and photographed. Fuels also were designated as brush, switch cane, or grass types, depending on the proportion of brush species, switch cane, and grasses in the composition.

Brush types are composed mainly of common gallberry, tall gallberry, white bay, redbay, loblolly-bay, swamp cyrilla, and fetterbush. Switch cane types are composed principally of reeds and minor amounts of common gallberry, common greenbrier, redbay, and white bay. Only one grass type, composed mostly of wire grass, was identified.

3/ The blowup potential is defined in terms of the ember lifting power of the convection column over a high intensity fire and is thus closely related to the capacity of such a fire to spot. Numerically, the blowup potential is equal to the quantity $(w/w_o)^2$, where w is the weight of the fuel and w_o is a reference fuel weight. In this study, which assumes the worst possible burning conditions, w is the total weight of the fuel. Under severe conditions all of the fuel is consumed and the maximum amount of energy released. A more detailed account of these concepts is given in a later section.

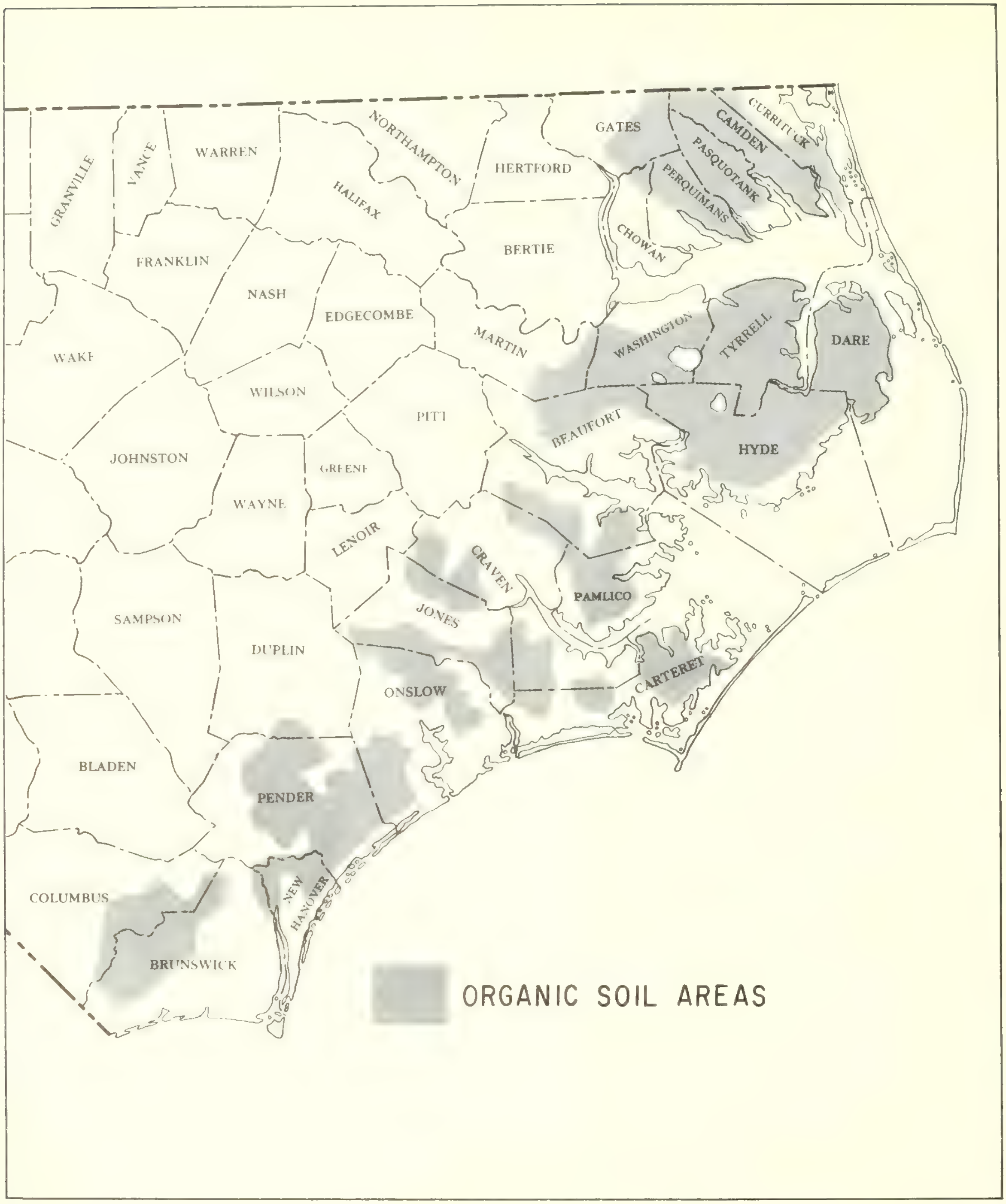

Figure 1.--Locations of principal organic soil areas in eastern North Carolina.

The understory species on pocosins, particularly the shrubs, generally grow in clumps, probably because of recurrent fires. Intense surface fires and brush crown fires, although hot and consuming, do not often kill the plant roots. As a result, the shrubs sprout prolifically. The clumps may vary in size from about 8 inches in diameter at the ground to 3 feet or more, as in the case of loblolly-bay. The area covered by brush clump crowns may vary from about 1 square foot to 60 or more square feet. Except for swamp cyrilla and honeycup, most of the more common species of pocosin vegetation are evergreen. The foliage of reeds cures on the canes in the winter.

Sampling the Understory Vegetation and Litter

Fuel weights were obtained from three 1/100-acre square plots and two 1-milacre plots laid out in each type, the latter to determine the feasibility of using smaller plots in future sampling. These smaller plots were only slightly larger than individual brush clumps. Average weights of the large plots and the small plots were very little different so all plots were combined for the analysis.

The vegetation was cut 1 inch above ground level, separated by species, and weighed. Pond pines no taller than the brush and the few dead standing plants were included with the understory. A sample of each species, usually a whole bush, was taken at the time of weighing for moisture content determination. A milacre plot of litter[4/] was collected and weighed from each of the 1/100-acre plots after the vegetation was removed. Fresh weights of each species and the litter were converted to ovendry weight in tons per acre by the following formula:

$$W_d = \frac{W_g}{20(100+m)A}$$

where W_d is the ovendry weight of the fuel component in tons per acre, W_g is the green weight of the fuel component on the plot in pounds, m is the moisture content in percent of ovendry weight determined by ovendrying a randomly selected small sample at 102° C., and A is the plot area in acres. The total fuel weight in tons per acre ovendry was obtained by adding up the individual species weights and the weight of the litter. Average weights of the 5 plot replications were used in the analysis.

Sampling the Overstory

Most of the fuel types appeared to have a characteristic pine overstory or no overstory, probably the reflection of site. However, pond pine stands of different diameters and densities were observed to occur occasionally over all understory fuel types. This seemed to rule out sampling the overstory on a plot basis along with the understory. A simple method of estimating the contributions of the pine crowns to total fuel weights was devised.

4/ Includes both the litter layer and the duff layer, defined by the U. S. Forest Service respectively as, "the top layer of the forest floor, composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves or needles, little altered in structure by decomposition," and "the partly decomposed organic material of the forest floor beneath the litter of freshly fallen twigs, needles, and leaves" (17).

A companion study (18) provided the basis for table 1; the contribution of the pine foliage can be estimated readily from average stem diameter and degree of stocking. The technique of estimating tree crown weights from stem dimensions is well established (10, 11, 15, 16). During very intense fires, twig ends are consumed in addition to the foliage, but as a rule, the contribution of the branchwood to total fuel weight consumed is small and can be ignored. Also, there is a compensating effect in that brush stems larger than 1 inch in diameter were weighed with the understory vegetation but are not always totally consumed in blowup fires.

Crown weight studies were not made for longleaf pine or loblolly pine because in only 3 of the 14 fuel types are either of these species important components of the overstory. In only one of these three types is longleaf pine usually present. The needles seldom burn because the understory wire grass fuel usually is not heavy enough to cause crowning. Table 1 can be used to estimate the foliage contribution of all three species to total fuel weight with good accuracy.

Table 1.--Ovendry foliage weight of pond pine by stem diameter and stocking

D.b.h. (inches)	Number of trees per acre									
	10	20	30	40	50	60	70	80	90	100
	- - - - - - - - - - - - Tons per acre - - - - - - - - - - - -									
2	--	--	--	--	--	--	--	--	--	0.1
3	--	--	--	--	--	--	0.1	0.1	0.1	.2
4	--	--	--	0.1	0.1	0.2	.2	.2	.2	.3
5	--	--	0.1	.2	.2	.2	.3	.3	.3	.4
6	--	0.1	.2	.2	.3	.3	.3	.4	.5	.5
7	--	.1	.2	.3	.3	.4	.5	.5	.6	.7
8	--	.2	.3	.3	.4	.5	.6	.7	.8	.9
9	0.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
10	.1	.3	.4	.5	.6	.8	.9	1.0	1.1	1.3
11	.1	.3	.4	.5	.7	.8	.9	1.1	1.2	1.4
12	.2	.3	.5	.6	.8	.9	1.1	1.2	1.4	1.5
13	.2	.4	.5	.7	.9	1.1	1.2	1.4	1.6	1.8
14	.2	.4	.6	.8	1.0	1.2	1.4	1.6	1.8	2.0
15	.2	.5	.7	.9	1.1	1.4	1.6	1.8	2.0	2.3

Total Weight Classes and Blowup Potential

The final steps in rating the 14 fuel types are expressed in tables 2 and 3. Table 2 expresses basic physical relationships and does not depend on any given fuel type. The first column in this table shows fuel weight classes set up in a convenient but arbitrary physical breakdown. The weight range within a class bears an approximately constant ratio to the midpoint weight of the class. The blowup potential is defined by the dimensionless ratio $(w/w_o)^2$, where w is fuel weight and w_o an arbitrary reference weight which can be assigned any convenient value. A value of w_o of 6 tons per acre was chosen because the probability of blowup fires decreases rapidly when w_o is less than 6 tons per acre. The class range of $(w/w_o)^2$ corresponding to each fuel weight class is shown in the second column of table 2. Descriptive designations for the blowup potential classes are listed in the third column.

The first, second, and third columns of table 3 give the symbol, name, and total fuel weight, respectively, of the 14 principal fuel types in the organic soils region. The blowup potential $(w/w_o)^2$ is given for each type in numerical form in column 4. Comparing column 3 in table 3 with column 1 in table 2 gives the appropriate descriptive designation of the blowup potential for the different types. These are listed in the fifth column of table 3.

Because the fuel weight classes of table 2 are independent of the different fuels listed in table 3, a specific fuel type does not necessarily have a fixed relationship to a given fuel weight class or its associated blowup potential. For example, a fire could burn over an area and consume some of the fuel, thereby reducing the fuel weight. If the fire was not intense enough to change the type characteristics (species composition, apparent density, and height), then for that particular area the blowup potential for the type might drop from high to medium high or even lower. Values of the blowup potential for the different fuel types in table 3 should, therefore, be regarded as estimates which will change as the quantity of fuel changes.

Table 2.--Blowup potential ratings for various fuel weight classes

Fuel weight classes (tons per acre)	Blowup potential	
	Range of $(w/w_o)^2$ 1/	Description
2.9 - 4.0	0.23 - 0.45	Very Low
4.1 - 5.7	0.46 - 0.91	Low
5.8 - 8.0	0.92 - 1.79	Medium Low
8.1 - 11.0	1.80 - 3.39	Medium
11.1 - 16.0	3.40 - 7.15	Medium High
16.1 - 23.0	7.16 - 14.7	High
23.1 - 32.0	14.8 - 28.4	Very High

1/ Reference weight, w_o, is 6.0 tons per acre.

Table 3.--Estimated blowup potential ratings for various pocosin fuel types

Symbol 1/	Name	Total 2/ fuel weight	Blowup potential	
			$(w/w_o)^2$	Description
		Tons per acre		
G-5	Wiregrass	4.5	0.55	Low
P-5	Low pocosin--open	5.7	.90	Low to Medium Low
GB-7	Grass--low brush	6.4	1.14	Medium Low
RG-7	Low reeds--grass	6.5	1.17	Medium Low
P-10	Low pocosin--dense	8.4	1.99	Medium
B(SR)-10	Brush (sand ridge)	8.6	2.02	Medium
RB-10	Medium reeds--brush	8.8	2.13	Medium
BG(SR)-10	Low brush--grass (sand ridge)	8.8	2.16	Medium
BG-10	Medium brush--grass	9.4	2.43	Medium
R-10	High reeds	3/ 10.1	2.84	Medium
R-14	Very high reeds	3/ 13.2	4.82	Medium High
P-14	High pocosin	3/ 15.0	6.25	Medium High
B-20	High brush	3/ 17.3	8.35	High
B(S)-20	High brush (swamp)	3/ 21.0	12.2	High

1/ G = wiregrass; P = pocosin; B = brush; R = reeds (switch cane); S = swamp; SR = sand ridge; the numerals 5, 7, etc. are the approximate midpoints of the total fuel weight classes in tons per acre as set up in table 2.

2/ Total fuel weights are averages of sampled weights.

3/ If an overstory is present, add to the tabular value a correction for foliage weight from table 1. Check this corrected total weight figure against column 1, table 2, to obtain the appropriate blowup potential.

The weights of the fuel for the different types given in table 3 represent the litter and understory fuel only. Although many high intensity fires crown only sporadically in most of the southern pine types, the highest intensity fires may consume the foliage. Hence, for extreme conditions the estimated foliage weights from table 1 should be added to the total fuel weight in table 3. The correction is relatively small. Also, because extensive crowning is unlikely in the lighter fuels even under severe conditions, the foliage weight could probably be disregarded for litter and understory fuel weights less than 10 tons per acre. One exception would be for dense even-aged reproduction stands 15 to 30 feet in height that will crown readily even if the ground fuel is light. However, this type is not common in the organic soils region of North Carolina.

It should be emphasized that the fuel classes described in this paper are based on one fuel factor, total fuel energy[5/] (and hence total fuel weight), and for this reason apply only to the most severe conditions of fuel dryness. Under these conditions practically all of the fuel burns, releasing the total energy which feeds into the base of the convection column. However, the concept will be applicable under all weather conditions as soon as sufficient information is available on the remaining fuel factors--primarily the combustion rate and the fuel energy available for convection, both of which depend on fuel size, fuel arrangement, and fuel moisture content. In less severe fire weather situations, the fuel weight w would then become the weight of fuel whose energy is available for convection. This might be far less than the total fuel weight. For example, in an area where the total fuel weight is 25 tons per acre it might be possible under some weather conditions to have a fire that would burn only 3 tons per acre in a time short enough for the energy to flow into the convection column (provided a convection column could exist).

5/ The amount of energy released if all of the fuel is consumed by a fire. This and the other five fuel factors are described in greater detail in a later section.

Identification of Fuel Types

The following key, photographs (figures 2 to 15), and accompanying descriptions give a more detailed account of the 14 fuel types and should aid in their identification.

Key for the Identification of Fuel Types[6/]

A. Grass Type. Occurring on mineral soils; a wire grass-common gallberry mixture; average $1\frac{1}{2}$ feet high; generally found in association with the longleaf pine timber type; 4.5 tons per acre.	G-5
A. Switch Cane Types. Generally occur on organic soils having fair internal drainage and 40 to 50 percent organic matter content in the upper 4 inches of soil; species composition 70 to 100 percent reeds in association with varying amounts of greenbrier, common gallberry, white bay and redbay, and a pond pine overstory.	4
A. Brush Types. Occurring on mineral and organic soils, composed principally of low and tall woody shrubs, small hardwood trees, and varying amounts of grass and herbaceous vegetation but with little or no reeds in composition, may have loblolly pine or pond pine overstory.	1
1. Occurring on mineral soils, low sand ridges adjacent to pocosins; composition chiefly a mixture of sweetgum, blackgum, myrtle, and swamp maple, 4 to 6 feet tall, with a lower stratum 1 to 2 feet tall of grasses and herbaceous vegetation; 8.7 tons per acre.	BG(SR)-10, B(SR)-10
1. Occurring on organic soils, pocosins, swamps, or bays; does not include cypress or gum swamps.	2
2. Occurring mostly on the more shallow, poor to fairly well drained organic soils, 6 to 24 inches deep; 30 to 50 percent organic matter content in the upper 4 inches of soil; average height of the understory varies from 4 to 14 feet.	3

6/ Weights given in the key are total fuel weights and are averages of sampled weights.

2. Occurring mostly on deeper, poorly drained organic soils usually 2 feet or more in depth; mostly peats and mucks with more than 80 percent organic matter content.

Composed principally of 60 percent swamp cyrilla, and 40 percent fetterbush, common gallberry, honeycup, leatherleaf, and sheep laurel, in equal amounts; average height of brush 3 feet, open habit of growth; widely scattered, short (10 to 12 feet tall) pond pine overstory; 5.7 tons per acre; open low pocosin. P-5

Chief species in the composition are 35 percent swamp cyrilla, 35 percent honeycup, 25 percent common gallberry and fetterbush, with an occasional large clump of loblolly-bay scattered throughout; average height of brush 4 feet, dense habit of growth; pond pine overstory similar to that in P-5; 8.4 tons per acre; dense low pocosin. P-10

3. Organic soil layer mostly 8 to 24 inches deep; tall shrub understory stratum.

Species composition 50 percent swamp cyrilla, 25 percent loblolly-bay, 15 percent common gallberry, 10 percent greenbrier, white bay, and redbay; good vertical continuity within the understory stratum due to abundant greenbrier and pine needle drape; brush height ranges from 2 to 16 feet with the average about 14 feet; 15.0 tons per acre; high pocosin. P-14

Species composition 50 percent fetterbush, 30 percent tall gallberry, dangleberry, and loblollybay, 20 percent white bay, greenbrier, and swamp cyrilla; a very dense mass due to the closeness of the stems; height range 4 to 12 feet, average about 8 feet; 17.3 tons per acre. B-20

Species composition 85 percent swamp cyrilla, 10 percent blackgum, and 5 percent common gallberry, white bay, and fetterbush; fewer but larger stems permit relatively easy travel through the type; height range of 5 to 14 feet with the average about 13 feet; 21.0 tons per acre. B(S)-20

3. Organic soil layer usually 6 to 8 inches deep; areas supporting these types usually have been logged.

Average height of brush 4 feet; species composition 60 percent grasses and herbaceous vegetation, 20 percent common gallberry, and redbay, 20 percent greenbrier, honeycup, blackgum, and fetterbush; recently logged, logging trails support dense grass stands; 6.4 tons per acre. GB-7

Average height of brush 5 feet; species composition 40 percent swamp cyrilla and redbay, 45 percent common gallberry, blackgum, sweet pepperbush, and greenbrier, 15 percent grasses and herbaceous vegetation; older logging; 9.4 tons per acre. BG-10

4. More than 80 percent switch cane in composition, chief associates are common gallberry and greenbrier; average height of the reed stratum is 10 feet, although many individual stalks may exceed 12 feet; reed stems at soil surface range from 1/2 to 3/4 inch in diameter; 13.2 tons per acre. R-14

4. Approximately 70 to 80 percent reeds in composition, principal associates common gallberry, fetterbush, white bay and redbay; average height of the reed stratum is less than 8 feet.

   5. Reeds less than 5 feet tall.

      Average height of reed 4 feet; species composition 70 percent reed, and grasses, with clumps of common gallberry, fetterbush, white bay, redbay, and grass areas making up the remaining 30 percent; usually the more recent (2 to 3 years) logged or burned reed areas; 6.5 tons per acre. RG-7

      Average height of reed 5 feet; species composition 80 percent reed, 10 percent common gallberry, greenbrier, and miscellaneous shrubs, 10 percent grasses and herbaceous vegetation mostly in old logging trails; shrub clumps are larger and reed stems are closer together than in RG-7; 8.8 tons per acre. RB-10

   5. Average height of reed 7 feet, although individuals may go to 9 feet; species composition 80 percent reed; common gallberry and greenbrier are major associates; 10.1 tons per acre. R-10

Figure 2. - Fuel type G-5 (wiregrass). Low blowup fire potential.

TYPE G-5 (WIREGRASS)

Ovendry weight	Tons per acre
Vegetation	1.54
Litter	2.92
Total	4.46

Fuel type G-5 occurs in association with longleaf pine in eastern North Carolina. These areas are important from the fire standpoint because they are often adjacent to pocosin areas and also because the fast-drying grass fuels can burn vigorously at any time of the year. Fires in this type have been known to occur only a few hours after heavy rains.

The soil is a sand with a very low organic matter content.

The principal species in the understory composition are wire grass, approximately 60 percent; common gallberry, 20 percent; and bracken fern, 20 percent. Scattered throughout the type are an occasional redbay bush and numerous herbaceous species. Bracken fern and common gallberry average $1\frac{1}{2}$ feet tall and the wire grass blades are generally $1\frac{1}{2}$ to 2 feet long. The wire grass appears shorter because the stems bend over and form a loose mat covering the area. The base of the wire grass clumps may average 3 to 4 inches in diameter, but these are usually not visible until after a fire.

During the late fall and early spring, wiregrass areas assume a brownish cast because of heavy longleaf pine needle fall and the curing of the wire grass.

The total weight figure represents the growth of the understory vegetation for 2 years. Older roughs may yield an additional 2 or more tons of ovendry material per acre. Generally most of the wiregrass areas are under management and are prescribed burned at 2 to 3 year intervals.

The overstory stands of longleaf pine are open and may contain groups of two or more age classes.

Figure 3.--Fuel type P-5 (low pocosin - open). Low to medium low blowup fire potential.

TYPE P-5 (LOW POCOSIN - OPEN)

Ovendry weight	Tons per acre
Vegetation	2.06
Litter	3.62
Total	5.68

Fuel type P-5 consists mainly of low shrub species that range from 1 to 3½ feet high. P-5 usually occurs on peat or muck soils having an organic matter content of 90 percent or more. The soil organic layer may be 2 feet or more in depth.

Principal species in the composition are swamp cyrilla, 60 percent; fetterbush, 10 percent; common gallberry, 10 percent; and honeycup, 10 percent. The remaining 10 percent consists of greenbrier, leatherleaf, redbay, and pond pine sprouts. The two largest contributors to total ovendry weight are swamp cyrilla and fetterbush which account for 60 percent of the total weight.

The soil surface in the type is characterized by brush hummocks averaging 6 inches high and spaced at approximately 1½-foot intervals. The area between hummocks is soft and does not offer much support to foot or equipment travel. From an over-all view the type appears as an even and homogeneous mixture.

The litter is generally 1 to 2 inches deep and is concentrated for the most part in the depressions between the hummocks.

The overstory consists of widely scattered pond pine of poor form that seldom exceed 15 feet in height. Much of the pine is of sprout origin and the area is considered noncommercial timberland.

The low and scattered nature of the shrub clumps makes this type very easy to walk in. It represents a brush growth and litter accumulation of 3 years.

Figure 4.--Fuel type GB-7 (grass - low brush). Medium low blowup fire potential.

TYPE GB-7 (GRASS - LOW BRUSH)

Ovendry weight	Tons per acre
Vegetation	2.89
Litter	3.55
Total	6.44

Fuel type GB-7 is a low brush type in which the individual species usually do not exceed a height of 3 or 4 feet. Generally, this type is found on the shallower organic soils (6- to 8-inch-deep organic layer). Type GB-7 is generally the result of a recent disturbance by fire or logging and is characterized by a composition of approximately 60 percent grasses and herbaceous species, 10 percent common gallberry, and 10 percent redbay. Numerous other species, including greenbrier, honeycup, blackgum, dangleberry, bracken fern, sweet pepperbush, chokeberry, myrtle, and swamp cyrilla, are associated in varying amounts. Thirty-seven percent of the vegetation ovendry weight is in grasses and herbaceous species, 35 percent in common gallberry and redbay, and 28 percent in the remaining species. Generally, if the areas have been logged, the grasses and herbs are most common in old skid trails, whereas the woody shrubs are found in clumps throughout the type.

Litter depth varies from ½ inch in old skid trails to about 1 inch beneath the brush clumps.

No difficulty is experienced in traveling through the type on foot. Equipment trafficability is also good.

Figure 5.--Fuel type RG-7 (low reeds - grass). Medium low blowup fire potential.

TYPE RG-7 (LOW REEDS - GRASS)

Ovendry weight	Tons per acre
Vegetation	3.91
Litter	2.57
Total	6.48

Type RG-7 consists mainly of low reeds that average 4 feet in height. Reeds and grasses account for roughly 70 percent of the cover and about 77 percent of the total vegetation ovendry weight. Associated species include common gallberry, fetterbush, white bay, redbay, myrtle, blackgum, and chokeberry in roughly equal amounts.

The type generally occurs on fairly well-drained, shallow organic soils having an organic matter content of 40 to 50 percent.

As a rule these areas are the result of recent disturbances by either fire or logging and represent an understory growth of 2 to 3 years. Many of the logging trails contain dense stands of grass and low herbaceous species with reeds and brush species encroaching.

Current litter, mainly reed foliage, remains fluffy until compacted by winter rains and is generally 1 to 2 inches deep.

Access to the type is relatively easy, particularly along the old logging trails. Very little difficulty is encountered in operating equipment in this type, even when the water table is high, because of the excellent support of the reed rhizomes.

Figure 6.--Fuel type P-10 (low pocosin - dense). Medium blowup fire potential.

TYPE P-10 (LOW POCOSIN - DENSE)

Ovendry weight	Tons per acre
Vegetation	4.00
Litter	4.45
Total	8.45

Type P-10 is very similar to P-5 in species composition and height, but markedly different in density. Brush clumps are close together and at the base average 8 to 10 inches in diameter. Shrub heights range from 1 to 4 feet and average about 4 feet.

The principal species in the composition are swamp cyrilla, 35 percent; honeycup, 35 percent; fetterbush, 15 percent; and common gallberry, 10 percent. The remaining cover consists of chokeberry, redbay, white bay, bracken fern, and sheep laurel, with considerable amounts of greenbrier intertwining among all species. Roughly 82 percent of the total ovendry weight is contributed by swamp cyrilla, honeycup, and fetterbush. In addition, widely scattered clumps of loblolly-bay are present.

The overstory is widely scattered pond pine similar to that described under type P-5.

Average litter depth is 1 inch, for the most part is evenly distributed, although it may be somewhat deeper in the shallow depressions between brush clumps. Total fuel weight represents a brush growth and litter accumulation of 8 years.

The type is moderately easy to walk in and trafficability for foot travel and equipment is aided by the close spacing of the brush clumps.

Figure 7. --Fuel type B(SR)-10 (brush - sand ridge). Medium blowup fire potential.

TYPE B(SR)-10 (BRUSH - SAND RIDGE)

Ovendry weight	Tons per acre
Vegetation	4.14
Litter	4.41
Total	8.55

Type B(SR)-10 is a sand ridge type found along the fringes of the pocosins. Although it does not occur on organic soils, it is important because many fires start in these areas and run into the pocosins.

Principal species include swamp maple, blackgum, sweetgum, myrtle, dangleberry, common gallberry, sweet pepperbush, and smooth sumac. Although B(SR)-10 and BG(SR)-10 appear to be distinctly different, they contain approximately the same total ovendry weight and the same species. B(SR)-10 has a smaller percentage of grasses and herbaceous species in the composition. B(SR)-10 appears less clumpy since it usually occurs on older logged areas and a smaller proportion of its weight is found in the litter which is well decayed logging slash. BG(SR)-10, on the other hand, is less compact and more clumpy. Also, B(SR)-10 has a height range from 1 to 7 feet as compared to 2 to 6 feet in BG(SR)-10.

The major distinction between the types is the number of undisturbed years. B(SR)-10 is an older logged type which has had about 6 years of healing over, whereas BG(SR)-10 is the condition about 2 years after logging.

Both types are easily accessible by foot or equipment and good trafficability is afforded heavy equipment.

Figure 8. - Fuel type RB-10 (medium reeds - brush). Medium blowup fire potential.

TYPE RB-10 (MEDIUM REEDS - BRUSH)

Ovendry weight	Tons per acre
Vegetation	4.70
Litter	4.05
Total	8.75

Fuel type RB-10 is a medium dense reed type averaging 5 feet tall, usually found on shallow, fairly well-drained organic soils. A few individual reed stalks may reach 6 feet in height.

The type is composed of reed, 80 percent; common gallberry, 10 percent; and associated species, such as swamp cyrilla, fetterbush, bracken fern, chokeberry, redbay, and grasses making up the remaining 10 percent. Reed and grasses compose 84 percent of the total ovendry vegetation weight. Greenbrier is intertwined with the reed and brush, slowing down foot travel through this type.

The litter is composed principally of the current year's reed foliage and may form a layer 3 to 4 inches deep before it is compacted by rainfall.

The type appears to be almost pure reed, but closer observation reveals that common gallberry, fetterbush, and other shrubs are abundant. During late fall and winter RB-10 appears as a light buff mass because of the persistent dead leaf sheaths on the reed stalks.

Figure 9.--Fuel type BG(SR)-10 (low brush - grass, sand ridge). Medium blowup fire potential.

TYPE BG(SR)-10 (LOW BRUSH-GRASS, SAND RIDGE)

Ovendry weight	Tons per acre
Vegetation	2.90
Litter	5.94
Total	8.84

Type BG(SR)-10 is a sand ridge type found along the fringes of the pocosins. Although it does not occur on organic soils it is important because many fires start in these areas and run into the pocosins.

Principal species include swamp maple, blackgum, sweetgum, myrtle, dangleberry, common gallberry, sweet pepperbush, and smooth sumac. Although BG(SR)-10 and B(SR)-10 appear to be distinctly different, they contain approximately the same total ovendry weight and the same species. BG(SR)-10 has a greater percentage of grasses and herbaceous species in the composition. BG(SR)-10 appears more clumpy since it usually occurs on recently logged areas and a larger proportion of its weight is found in the litter which is partially decayed logging slash. B(SR)-10, on the other hand, is more compact and not so clumpy. Also, BG(SR)-10 has a height range from 2 to 6 feet as compared to 1 to 7 feet in B(SR)-10.

The major distinction between the types is the number of years left undisturbed. BG(SR)-10 is a recently logged type which has had about 2 years of healing over, whereas B(SR)-10 is the condition about 6 years after logging.

Both types are easily accessible by foot or equipment and good trafficability is afforded heavy equipment.

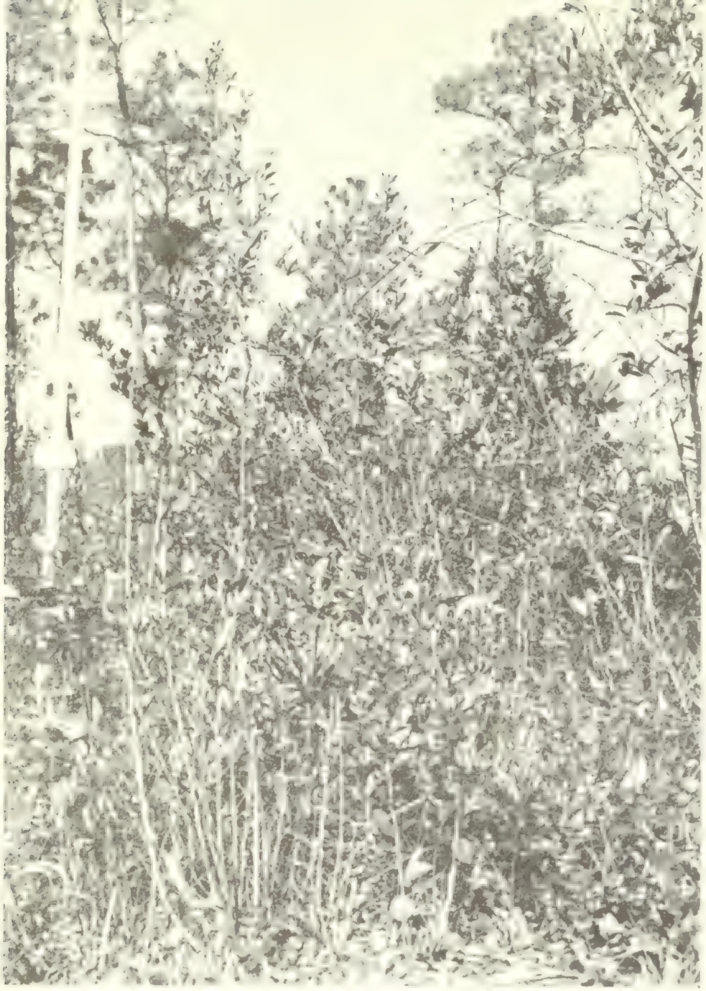

Figure 10.--Fuel type BG-10 (medium brush - grass). Medium blowup fire potential.

TYPE BG-10 (MEDIUM BRUSH - GRASS)

Ovendry weight	Tons per acre
Vegetation	4.78
Litter	4.59
Total	9.37

Type BG-10 is a medium height fuel type (2 to 6 feet, average 5 feet), generally found on logged over, shallow organic soils. It differs from GB-7 in that the percent of grasses and herbaceous vegetation is reduced to about 15 percent. The most abundant shrubs in the composition are redbay, 20 percent; swamp cyrilla, 20 percent; greenbrier, 15 percent; sweet pepperbush, 10 percent; common gallberry, 10 percent; and blackgum, 10 percent. Swamp cyrilla and redbay contribute 47 percent of the vegetation ovendry weight; blackgum, 14 percent; common gallberry, 13 percent; and sweet pepperbush, greenbrier, and grasses, 21 percent.

The type appears clumpy but much less so than GB-7 since BG-10 is the result of earlier logging or fire. Old skid roads are generally grassed, with scattered shrubby species encroaching.

Litter depth varies from 3/4 to 1 inch and consists of grass and herbaceous material in the old skid roads and shrub foliage in the less disturbed areas.

Foot travel through the type is moderately easy.

Figure 11.--Fuel type R-10 (high reeds). Medium blowup fire potential.

TYPE R-10 (HIGH REEDS)

Ovendry weight	Tons per acre
Vegetation	6.06
Litter	4.01
Total	10.07

Fuel type R-10 is very similar to RG-7 and RB-10 in composition but reeds average about 7 feet in height and individuals up to 9 feet have been measured. Reed composes about 80 percent of the cover, with associated species of greenbrier, white bay, common gallberry, dangleberry, and loblolly-bay. Seventy-two percent of the vegetation ovendry weight is reed, with the remainder evenly divided among the associated species. The type is very difficult to walk in because of a heavy growth of greenbrier. In places this species forms an almost complete canopy across the tops of the reed. This canopy is usually characterized by abundant pine needle drape since type R-10 is generally found under medium-dense, mature or over-mature pond pine stands. The organic soil layer is usually between 2 and 3 inches in depth.

This type appears very homogeneous with only an occasional loblolly-bay or white bay overtopping the reed.

The litter is composed chiefly of reed foliage and pine foliage that may form a loose open layer 3 to 6 inches deep when newly fallen.

Trafficability for equipment is generally good because of the excellent support given by the dense mat of reed rhizomes and stalks.

Figure 12.--Fuel type R-14 (very high reeds). Medium high blowup fire potential.

TYPE R-14 (VERY HIGH REEDS)

Ovendry weight	Tons per acre
Vegetation	8.48
Litter	4.70
Total	13.18

Type R-14 is an almost pure reed type. The reed stratum averages 10 feet high but individual reeds may grow to a height of 12 feet. Openings throughout the type are usually vegetated with grass and low herbaceous species.

This type, like R-10, generally occurs under well-stocked mature and over-mature pond pine stands.

The litter is composed principally of pine needles and reed foliage in a layer 3 to 4 inches deep.

Travel through R-14 is rather difficult on foot because of the density of the reed stand, although equipment trafficability is aided by the stems and dense root mass.

Figure 13.--Fuel type P-14 (high pocosin). Medium high blowup fire potential.

TYPE P-14 (HIGH POCOSIN)

Ovendry weight	Tons per acre
Vegetation	5.95
Litter	9.05
Total	15.00

Type P-14 is a high brush type. Plants range in height from 2 to 16 feet with the average near 14 feet. The type generally occurs on soils having an organic layer 18 to 24 inches deep. P-14 is composed of 50 percent swamp cyrilla, 25 percent loblolly-bay, 15 percent common gallberry, 10 percent greenbrier and miscellaneous shrubs. Of the total vegetation ovendry weight, swamp cyrilla contributes 37 percent, common gallberry 15 percent, and redbay 15 percent. The remaining weight is composed of dangleberry, loblolly-bay, greenbrier, and fetterbush.

Type P-14 represents an undisturbed brush growth and litter accumulation for a 9-year period. The litter ranges from 4 to 6 inches deep. Generally the overstory is a medium density pond pine stand and as a result the understory is characterized by a moderately heavy pine needle drape. Movement through the type is very difficult because of the large amount of greenbrier present and the large number of closely packed stems.

Figure 14.--Fuel type B-20 (high brush). High blowup fire potential.

TYPE B-20 (HIGH BRUSH)

Ovendry weight	Tons per acre
Vegetation	11.98
Litter	5.36
Total	17.34

Type B-20 is a high brush type composed principally of 50 percent fetterbush, 10 percent tall gallberry, 10 percent loblolly-bay, 10 percent dangleberry, and minor amounts of white bay, honeysuckle, greenbrier, swamp cyrilla, honeycup, and sheep laurel. Height ranges from 4 to 12 feet with an average of 8 feet. Three species, fetterbush, tall gallberry, and loblolly-bay, account for 82 percent of the vegetation ovendry weight, with fetterbush comprising 44 percent of this figure.

The type generally occurs on the outermost fringes of natural drainages, on soils having an organic layer 10 to 12 inches deep.

Litter averages 2 inches in depth and is concentrated in depressions between the brush hummocks.

Like P-14, type B-20 is very difficult to travel through because of an abundance of greenbrier. When the water table is high equipment trafficability may be poor.

Figure 15. --Fuel type B(S)-20 (high brush - swamp). High blowup fire potential.

B(S)-20 (HIGH BRUSH - SWAMP)

Ovendry weight	Tons per acre
Vegetation	15.64
Litter	5.36
Total	21.00

Fuel type B(S)-20 is a high brush type generally found at the head of a natural drainage. It is composed principally of 85 percent swamp cyrilla and 10 percent blackgum; together they constitute 93 percent of the vegetation ovendry weight. Swamp cyrilla averages about 14 feet high and blackgum 12 feet. A large proportion of the stems at ground line are between $1\frac{1}{2}$ and 2 inches in diameter. Where a pine overstory exists, the type is characterized by a heavy needle drape.

From the roadside B(S)-20 appears massive and impenetrable but once inside the type foot travel is not too difficult because there are fewer but larger stems contributing to the total weight.

The soils here have an organic layer 15 to 18 inches in depth and are fairly well drained because they are close to natural waterways.

AN ENERGY BASIS FOR CLASSIFYING FUELS

Probably the most significant aspect of the behavior of a fire is its intensity or rate of energy output. Because of the chain reaction nature of fire propagation, and because of interactions between a fire and the environmental atmosphere, the relationships between fire intensity, rate of spread, the fuel factors, and the atmospheric factors are very complex. These relationships appear to be greatly simplified, however, by the recent development of energy concepts (2, 3, 4, 12, 13, 14) that may also have an important application in the measurement, rating, and classification of fuels.

The Energy Rate Number

The rate of a fire's energy output is closely related to the convective activity of a fire. The structure and nature of the convection is determined both by the rate of energy output of the fire and by the rate of flow of kinetic energy in the wind field above the fire. Especially important is the ratio of the two energy rates which may be defined as the energy rate number (13). The magnitude of this dimensionless number, both at the earth's surface and in the atmosphere aloft, appears to determine not only whether a convection column can or cannot exist but certain characteristics of the convection as well. Although precise values will have to be determined experimentally both in the laboratory and in the field, it is likely that a convection column can exist if the energy rate number is equal to or greater than 1.00 (energy output of the fire dominating). On the other hand, if the energy rate number is small, say, in the neighborhood of 0.05 or 0.10 (energy of the wind field dominating), the convection pattern would be a weak plume drifting downwind and maintaining contact with the ground. This plume would have but little organized upward flow of hot gases such as exists in the center of a well-formed convection column.

Basic Fuel Factors

An energy description of a complex heterogeneous fuel in terms of expected fire behavior requires several basic fuel factors. These are:

1. Total fuel energy: the amount of energy released if all of the fuel is consumed; it is the upper limit of both the available fuel energy and the fuel energy available for convection.

2. Available fuel energy: defined as the amount of energy released by the fuel which actually burns.

3. Fuel energy available for convection: that portion of the available fuel energy which is fed into the base of the convection column.

4. The combustion period: the time required for a given fuel component to burn up completely.

5. Critical burnout time: the maximum length of time that a fuel can burn and still be able to feed its energy into the base of the forward-traveling convection column.

6. Quantity and quality of firebrand material available for spotting.

An energy description of fuels in terms of fire behavior is considerably simpler when burning conditions are severe than when they are not. This is also true for some fuel types such as those in the pocosin areas which have no large fuel components that burn for long periods.[7/] It thus appears that one of the simplest descriptions of a fuel on an energy basis would be for a pocosin type under the worst burning conditions. In this case available fuel energy, fuel energy available for convection, and total fuel energy are essentially the same because for high-intensity fires the combustion periods for the various fuel components would be less than the critical burnout time. Hence, under these conditions, the basic fuel factors reduce to (1) total fuel energy, (2) combustion period, and (3) quantity and quality of firebrand material. Total fuel energy is thus a major factor in blowup fires and for this reason its study was started first.

Ember Lifting Power and Blowup Potential

There are several possible ways of comparing the effect of quantity of fuel on fire behavior. One of the best ways is by means of an index directly proportional to a fire's ember lifting power because spotting is a dominating behavior characteristic of large fires (13). This is given by the scaling equation

$$W/W_o = (I/I_o)^2 \, (D/D_o)^{-2} \qquad (1)$$

in which W_o is the weight and D_o the density of an ember which can just be supported by the updrafts in the convection column over a fire with a reference intensity I_o. The weight W and density D apply to an ember which can just be supported by the updrafts over a fire of any given intensity I. The fire intensity I is equal to the product of three quantities: the heat yield H, the fuel weight w, and the rate of spread r. Equation (1) can thus be written as

$$W/W_o = (H/H_o)^2 \, (w/w_o)^2 \, (r/r_o)^2 \, (D/D_o)^{-2} \qquad (2)$$

For a given kind of ember material, the ratio D/D_o can be taken as unity. If the heat yield is approximately the same for the fuels of two different fires then H/H_o is also unity. If the rate of spread is the same for the two fires the ratio r/r_o is unity and the relative ember lifting power of two different fires is equal to $(w/w_o)^2$ which is the desired index. This quantity is designated as the blowup potential and is plotted in figure 16 as a function of w.

7/ A possible exception is the organic soil itself when it is dry enough to burn but this causes no great difficulty. One of the most significant of the fuel factors is the fuel energy available for convection and a thin layer of the organic soil contributes to this energy. The burning of the deeper layers would be too slow to appreciably influence fire behavior.

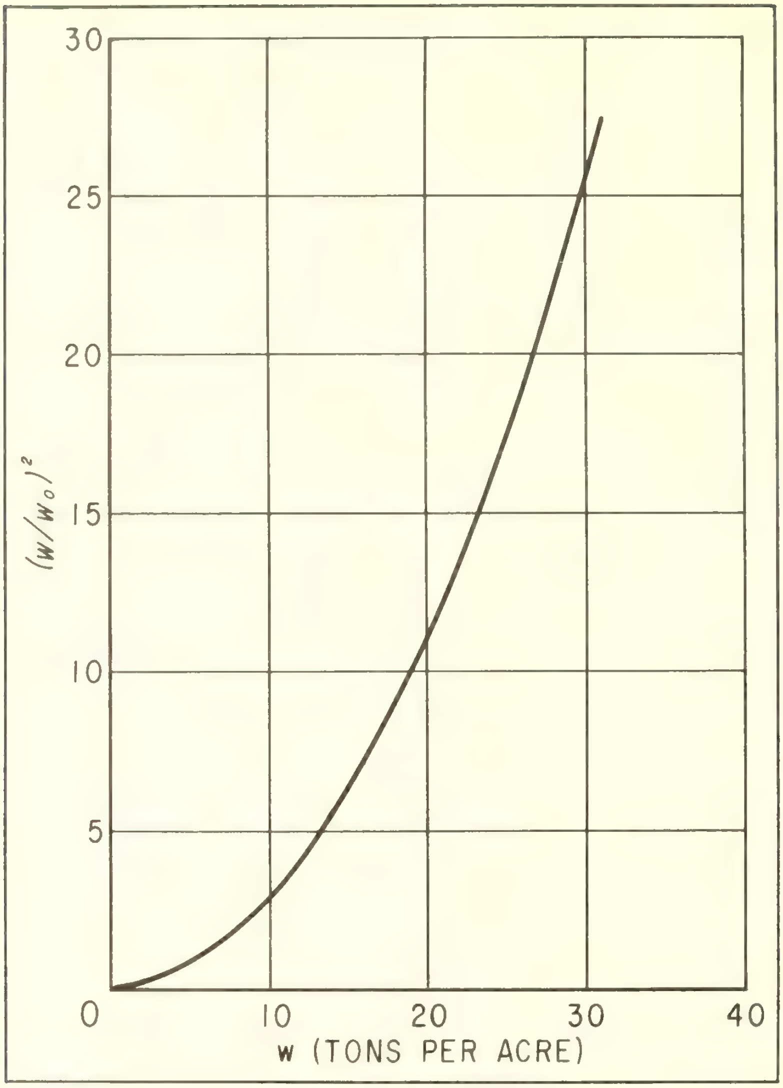

Figure 16.--Blowup potential, $(w/w_o)^2$, plotted as a function of fuel weight, w, for a reference fuel weight, w_o, of 6.0 tons per acre.

The blowup potential is only one of a number of basic quantities which determine the ultimate behavior of a given fire. However, in combination with the combustion rate[8] it promises to give an effective quantitative energy description of fuels that is needed before the probability of major fires can be established. In turn, an estimate of this probability will require that additional factors be brought in such as wind speed, and the vertical wind speed profile which determines how the energy rate number varies with height above the earth's surface.

8/ The combustion rate is defined as the rate of energy release per unit of burning area.

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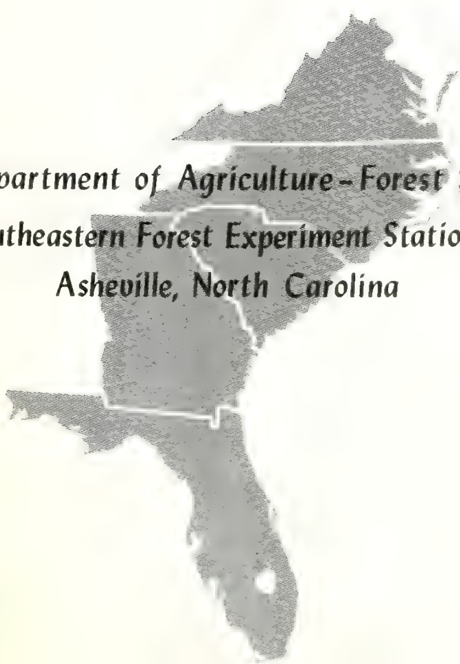
Board-foot and Cubic-foot Volume Computing Equations for Southeastern Tree Species

by

Mackay B. Bryan
and Joe P. McClure



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BOARD-FOOT AND CUBIC-FOOT VOLUME COMPUTING EQUATIONS FOR SOUTHEASTERN TREE SPECIES

by

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INTRODUCTION

Wide acceptance of Bitterlich's (2) method of sampling, popularized in this country by Grosenbaugh (3), with adaptations such as the variable plot used by Forest Survey in the Southeast, has opened a new era in forest surveying. The efficiency of these sampling methods, accompanied by the timely availability of electronic computing machines, has made it feasible to collect and retain large amounts of forest inventory information.

Each tree on the sample plot now can be treated individually, recording such descriptive data as species, tree quality, and crown class, along with stem dimensions, amount of cull, and rate of growth. This information can be transferred to individual punch cards with area information such as forest type, stand size, site quality, and stand condition. The method has greatly expanded the ability of the forest manager to analyze the situation in large forest holdings and that of the forest resource analyst to do so for a state or region. Still lacking, however, are volume equations that can provide precise volume estimates for individual trees to match this fund of detailed tree and area data.

The Forest Survey organizations of the Intermountain and Southeastern Forest Experiment Stations have used volume estimating equations for several years. Bennett, McGee, and Clutter (1), Langdon (4), and many others have used volume equations in the construction of volume tables. Most common have been adaptations of the D^2H equations described by Spurr (5), in which d. b. h. and merchantable length are the measured variables. Such equations prepared for uniform stands of one species, such as conifer plantations, may provide accurate estimates for individual trees. But exploratory work done by the authors with several variations of the D^2H equation failed, as a general rule, to provide the desired precision in natural stands of the Southeast. This was especially true of tests on hardwoods.

This paper presents equations that use one or more additional measured variables in an attempt to estimate individual tree volumes more accurately.

SOURCE OF TREE MEASUREMENT DATA

Nearly 10 years ago, a system was set up by Forest Survey at the Southeastern Station for defining and coding tree sections and recording their dimensions, gross volume, cull, log grade, utilization for timber products, etc. The system has been followed in two cull and log-grade studies and one utilization study in Virginia, two cull and log-grade studies and two utilization studies in North Carolina, one cull and log-grade study in South Carolina, one utilization study in Florida, and a utilization and volume-table study in Georgia. These mensurational studies varied in size from about 300 to 1,000 trees on 56 to 108 sample areas.

Individual tree volumes were obtained by the accumulation of section volumes for each sample tree.

EXPLORATORY WORK WITH EQUATION FORM

Tree measurement data for one softwood and one hardwood (loblolly pine and sweetgum) were studied in experiments with equation form. Multiple regression techniques were used to analyze the following board-foot and cubic-foot volume equations:

$$V_B = a+b_1(D^2H)+b_2(S^2H)+b_3(DSH)+b_4(H)+b_5\left(\frac{H}{D-S}\right)+b_6(D^2)+b_7\left(\frac{1}{D-8.9}\right)$$

$$V_C = a+b_1(D^2H_c)+b_2(D^2)+b_3(H_c)+b_4\left(\frac{H_c}{D}\right)$$

where:

V_B = Gross board-foot volume (International $\frac{1}{4}$-inch rule)

V_C = Gross cubic-foot volume to 4.0 inches outside bark (excluding bark)

D = Diameter at breast height or 1.5 feet above bottleneck for normally swell-butted trees 1/

S = Diameter inside bark at top of saw-log portion

H = Length of saw-log portion in feet

H_c = Length of cordwood section to 4.0 inches outside bark

The coefficients of multiple correlation derived for all possible combinations of variables were compared as a preliminary analytical procedure. Table 1 presents a summary of this test.

1/ For bottomland species such as cypress and tupelo with normal butt-swell extending above 3 feet, diameter should be measured 1.5 feet above noticeable swell or "bottleneck."

Table 1. --Coefficients of multiple correlation from initial tests on equation form

Species	Type of equation	Best R^2 without S	Best R^2 with S
Loblolly pine	Board-foot	96.8	98.5
	Cubic-foot	98.6	--
Sweetgum	Board-foot	95.5	98.2
	Cubic-foot	70.3	--

These tests and others involving range of accuracy, contribution of additional variables, and empirical accuracy of prediction indicated that an equation of the form $V = a+b(D^2H)$ might be acceptable for estimating both board-foot and cubic-foot volume of certain conifers. For other more variable species, particularly hardwoods, an additional stem dimension is required to compensate for differences in stem form that very commonly occur in trees of the same d. b. h. and merchantable length.

Different equation forms and choices of variables by species and tree size might be justified for specialized forest inventories. It is believed, however, that for extensive inventories such as those conducted by Forest Survey, it is best to settle on one or two equation forms. This is important from the standpoint of (1) training cruisers and maintaining accuracy in their work, and (2) programming and checking machine computations.

Diameter inside bark (d. i. b.) at a selected point on the stem was chosen as a third dimension (fig. 1). In the case of sawtimber trees, this point coinsides with the saw-log top. In pole trees and culls, it is the point of noticeable change in stem taper where such a point can be distinguished. When such a point cannot be distinguished, it is the midpoint of the stem. This third stem dimension was selected for the following reasons:

1. The upper limit of the saw-log portion commonly coincides with a point of noticeable change in stem taper. The more-or-less cylindrical saw-log portion often changes there to a cone-shaped upper stem.

2. D. i. b. at the saw-log top is one of the dimensions commonly considered by cruisers in establishing the limit of minimum saw-log merchantability.

ACCURACY OF D. I. B. ESTIMATES

The thought of using d. i. b. as a variable in volume equations immediately suggests the need for tests of the average timber cruiser's ability to estimate it. It appeared possible that d. i. b. estimates might be too inaccurate to be of value in refining volume equations. Consequently, two trial tests were made.

Preliminary Field Test

Eighty-five trees of various species, diameters, and heights were measured beforehand and marked to identify the point of d. i. b. measurement. A group of 11 Forest Survey cruisers were asked to estimate d. o. b. and d. i. b. at the point marked on each tree. The men differed in experience from a few months to over 3 years, but none had been trained in making d. i. b. estimates.

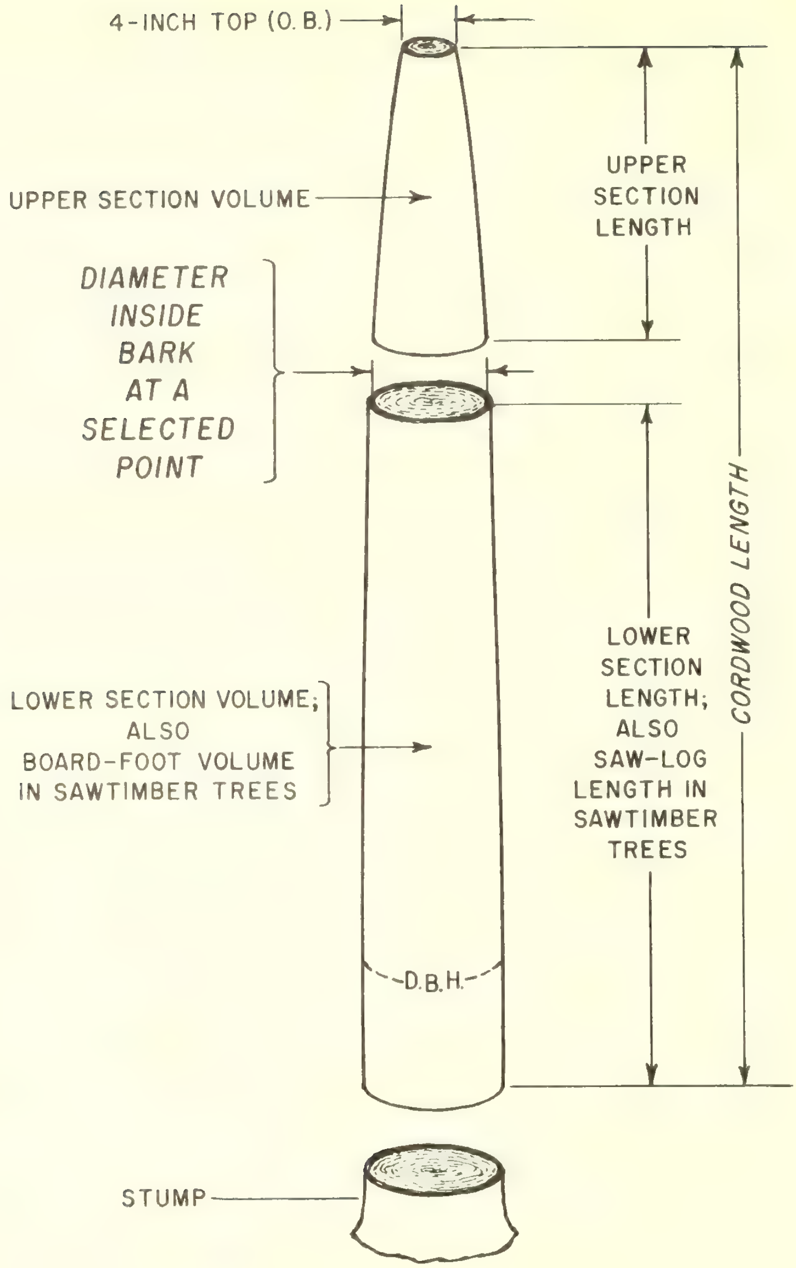

Figure 1. --The diameter inside bark at a selected point, when used with d. b. h., cordwood length, and saw-log length, adds to the precision of volume estimates.

The average error was 0.75 inch for d. o. b. and 0.76 inch for d. i. b. Only one estimator's error in d. i. b. averaged more than 0.90 inch. It was interesting to note that d. i. b. was estimated with approximately the same accuracy as d. o. b.

The preliminary tests indicated that d. i. b. would add to the precision of volume estimates except in the case of cubic-foot volume in small pole-timber trees.

A Test For Maximum Error

Although the preliminary test indicated that timber cruisers can estimate d. i. b. with acceptable accuracy, there was doubt as to the reliability of such a test in evaluating accuracy under normal field conditions. A second test was set up under conditions expected to provide the least accurate estimates that might be expected of Forest Survey crews. No special training or detailed instructions were given. All crews were simply given field plot sheets with an added space for top d. i. b. and were asked to begin recording it for all trees 5.0 inches d. b. h. or larger. The crews did not know that their estimates might be checked.

After the estimates had progressed for one month, 118 trees on a subsample of 16 plots were climbed to check the d. i. b. estimates. Results of this test showed an average error of 0.47 inch. The 6 men who had also taken part in the earlier test averaged 0.22 inch less error in the second test. Evidently some training has been gained from the earlier experience.

With field training and occasional checks, it is believed that cruisers should maintain an accuracy of d. i. b. estimates somewhat better than shown in the second test.

FINAL VOLUME ESTIMATING EQUATIONS

The final volume equations take the following form:

BOARD FEET $V_B = a + b_1 DSH + b_2 H$

CUBIC FEET $V_C = b_1 DSH + b_2 SU + b_3 (SU)^2$

where:

V_B = Gross board-foot volume (International $\frac{1}{4}$-inch rule)

D = Diameter at breast height or 1.5 feet above point of bottleneck for normally swell-butted trees.

S = Scaling diameter (d. i. b.) at the top of the lower section (also top of saw-log portion in sawtimber trees)

H = Length of lower section (also saw-log portion in sawtimber trees)

and

V_C = Gross cubic-foot volume to the 4.0-inch top outside bark, excluding bark volume

U = Upper section length in feet. This is the section from the top of the lower section to the 4.0-inch o. b. top.

The board-foot equation was weighted by the reciprocal of DSH. The cubic-foot equation was handled in two parts separating volume in the lower section from volume in the upper section. The former, $V = b_1DSH$, was weighted by the reciprocal of DSH. The latter, $V = b_2SU+b_3(SU)^2$, was weighted by the reciprocal of SU.

The coefficients for gross board-foot (International $\frac{1}{4}$-inch rule) volume equations of the form $V_B = a+b_1DSH+b_2H$ for the principal southeastern species are listed in table 2. The equation coefficients for gross cubic-foot volume (excluding bark) to a 4.0-inch top outside bark are listed in table 3.

The cubic-foot equation $V_C = b_1DSH+b_2SU+b_3(SU)^2$ can be used in two segments. The first portion, b_1DSH, supplies the volume of the lower section in all size trees. The remainder, $b_2SU+b_3(SU)^2$, computes the volume of the upper section in all size trees.

Table 2. --Board-foot volume equation coefficients for principal species of the Southeast

Species	Number of trees used	a	b_1	b_2
Longleaf pine	101	-11.89	0.035955	-0.0686
Slash pine	87	-09.40	.035909	-0.2762
Loblolly pine	323	-13.21	.038112	-0.2644
Shortleaf pine	65	-11.07	.035355	-0.0773
Pond pine	49	-10.07	.035584	-0.2131
Virginia pine	156	-03.05	.037057	-0.3735
White pine	126	-05.97	.038338	-0.4564
Baldcypress	87	-17.12	.037542	-0.1716
Pondcypress	69	-06.79	.033052	-0.2804
Blackgum	98	-12.86	.037147	-0.3387
Yellow-poplar	83	-14.93	.041232	-0.5470
Sweetgum	133	-07.52	.040328	-0.7234
Red maple	67	-00.42	.040385	-1.0743
White oak	77	-04.02	.039088	-0.6716
Chestnut oak	109	-08.61	.039357	-0.4924
Northern red oak	59	-04.60	.040752	-0.8123
Scarlet oak	117	-05.44	.039133	-0.6653
Hickory	72	-05.26	.038061	-0.4626
Ash	45	-02.44	.038834	-0.7236
Birch	47	-04.54	.038733	-0.5999

Table 3. --Cubic-foot volume equation coefficients for principal species of the Southeast

Species	Number of trees used	b_1	b_2	b_3
Longleaf pine	191	0.005127	0.01951	0.00002740
Slash pine	203	.004866	.01712	.00003942
Loblolly pine	363	.005106	.01941	.00004870
Shortleaf pine	114	.005045	.01551	.00006159
Pond pine	58	.004956	.01667	.00005722
Virginia pine	236	.005287	.01927	.00004910
White pine	130	.005337	.02028	.00003668
Baldcypress	100	.005157	.02275	.00002719
Pondcypress	95	.004951	.01830	.00003344
Blackgum	141	.005056	.01617	.00006025
Yellow-poplar	125	.005307	.01949	.00002839
Sweetgum	139	.005285	.02244	.00002658
Red maple	71	.005407	.02291	.00001495
White oak	92	.005312	.01907	.00002843
Chestnut oak	112	.005127	.02191	.00002040
Northern red oak	60	.005331	.01970	.00002550
Scarlet oak	125	.005224	.01907	.00002712
Hickory	73	.005218	.02099	.00002196
Ash	56	.005304	.01861	.00003298
Birch	50	.005383	.02168	.00001814

TESTS OF ACCURACY

Statistical Tests of the Volume Regression

The reliability of the board-foot and cubic-foot volume equations was tested for six commercially important species of the Southeast. Included were longleaf, shortleaf, and loblolly pines, blackgum, yellow-poplar, and white oak. Analyses of error were made at the 5-percent level. The half-widths of the confidence intervals for tree of mean size are given in table 4.

In addition, the equations were tested and found to be consistently reliable over the full range of tree diameters for each species.

Tests With Independent Samples of Trees

The most meaningful test of a volume equation is, of course, its performance in actual use. For that reason, several of the equations were checked to determine how well they estimated the volumes of measured trees other than those used in deriving them.

Table 4. --Statistical accuracy of volume equations for a few selected species

Species	Type of equation	Trees used in regression	Half width of confidence interval for tree of mean size 1/
		Number	Percent
Longleaf pine	Board-foot	101	1.72
	Cubic-foot	191	1.39
Loblolly pine	Board-foot	323	1.10
	Cubic-foot	363	.97
Shortleaf pine	Board-foot	65	4.46
	Cubic-foot	114	2.47
Blackgum	Board-foot	98	1.83
	Cubic-foot	141	2.80
Yellow-poplar	Board-foot	83	1.48
	Cubic-foot	125	2.06
White oak	Board-foot	77	1.61
	Cubic-foot	92	2.21

1/ This figure may be interpreted to mean that there are only 5 chances in 100 that the true volume of a tree of average size will differ from the predicted volume by more than the percent shown.

Trees used in these tests were measured on cutting operations in the Piedmont and mountains of Georgia entirely outside the area from which the sample tree measurements for the equations were obtained. The equations were found to be consistently accurate for trees of varying lengths over a range of diameters from 5 to 21 inches. Methods described by Spurr (5) were used to compute aggregate deviation and average deviation values, which are presented in table 5.

Table 5. --Tests of volume equations with independent samples of measured trees

Species	Trees used-- constructing the equation	Trees used-- in the test	Gross volume: Scaled	Gross volume: Computed	Error: Aggregate deviation	Error: Average deviation
	- - - Number - - -		- - - Volume - - -		- - - Percent - - -	
BOARD-FOOT EQUATIONS						
Loblolly pine	323	96	8,715	8,828	1.28	6.34
Shortleaf pine	65	54	4,142	3,956	-4.70	7.43
Blackgum	98	21	3,007	3,034	.89	6.23
Yellow-poplar	83	12	3,282	3,429	4.29	5.34
CUBIC-FOOT EQUATIONS						
Loblolly pine	363	189	2,110.7	2,198.6	4.00	6.19
Shortleaf pine	114	106	1,027.3	998.3	2.90	6.01
Blackgum	141	25	696.5	697.0	.07	5.75
Yellow-poplar	125	13	604.6	619.2	2.36	4.17

APPLICATION OF VOLUME EQUATIONS

The above tests indicate that satisfactory estimates of tree volume can be obtained with these volume equations. However, two restrictions must be observed if the equations are to be used most effectively:

1. The Merchantability Standards Observed by the Cruiser Should Match Those on Which the Equations are Based.

Table 6. --Minimum saw-log top by d. b. h. and broad species group
(In inches)

D. b. h.	Softwoods	Hardwoods
9	5.5	--
10	6.0	--
11	6.6	8.0
12	7.0	8.0
13	7.4	8.0
14	7.8	8.0
15	8.2	8.2
16	8.6	8.6
17	9.0	9.0
18	9.4	9.4
19	9.7	9.7
20	10.0	10.0
21	10.3	10.3
22	10.6	10.6
23	10.8	10.8
24	11.0	11.0
25	11.2	11.2
26	11.4	11.4
30+	12.0	12.0

The merchantability standards used in taking sample tree measurements were designed to coincide with general cutting practices in the Southeast. Softwoods 9.0 inches or larger and hardwoods 11.0 inches or larger having at least one 8-foot log and less than two-thirds cull in the saw-log portion were measured for board-foot volume. The upper limit of the saw-log portion was generally taken to a variable minimum top. However, excessive roughness or rot were limits to merchantability in some instances. Table 6 lists the variable minimum tops by d. b. h. and broad species group. Cubic-foot volume measurements were made on all sample trees 5.0 inches d. b. h. and larger. Merchantable cubic-foot volume was taken from a 1-foot stump to 4.0 inches outside bark.

2. Accurate Tree Volumes Depend on Accurate Tree Measurements

To take full advantage of the precision offered by the equations, trees should be measured as exactly as possible.

D. b. h. always should be measured to tenths of inches. For trees used in developing the regressions, d. b. h. was measured with a diameter tape whenever possible. In other cases two calipered diameters were averaged.

Lower section length and length to 4.0-inch top outside bark should be recorded in feet (the difference between these is upper section length). Professional cruisers should frequently check tree lengths with a hypsometer. It is recommended that they measure at least one or more trees in each clump and all extremely tall trees as a minimum. Those who estimate timber only occasionally should measure the lengths of all trees.

Cruisers should train themselves to estimate top d. i. b., making frequent checks unless an instrument is used to make this measurement (outside bark). Actual measurements following ocular estimates serve as the best training check. This can be done by climbing and measuring estimated trees

or by estimating standing trees on cutting operations and making check measurements as they are felled. Another method almost as effective is to stand off at varying distances from trees to estimate d. i. b. four or five feet above ground; then measure actual d. o. b. and bark thickness at that point.

Bark thickness within species usually is closely correlated with diameter of stem, although appearance of the bark's surface provides additional clues to its thickness. Knowledge of bark thickness can be gained by measuring it at points within reach on a range of tree sizes.

Timber cruisers should be expected to maintain an accuracy of ± 5 percent in nine out of ten estimates of d. i. b. after training and using the above mentioned methods of checking themselves.

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Effect of Burning on South Florida Range

by J. B. Hilmon & C. E. Lewis

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Effect of Burning on South Florida Range

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Livestock ranges in south Florida are burned during the winter season every 2 or 3 years to remove accumulated growth and "freshen" native forage plants for cattle. This practice increases variation in herbage volume and nutritive quality, and alters seasonal patterns of herbage growth. A period of no herbage volume immediately after a fire is followed by a brief period of low herbage volume-high nutritive quality and finally, by an extended period of high herbage volume-low nutritive quality.

Livestock range in south Florida "freshened" for cattle.

Recently burned native ranges are characterized by high quality-low volume herbage.

Davis and Kirk,[1] in tests at the Range Cattle Station, Ona, Florida, found that protein varied from 10 percent in very young wiregrass-type forage to 1.5 to 2.5 percent in old wiregrass. Phosphorus values were usually below 0.10 percent and often below 0.05 percent. Killinger[2] reported as much as 0.18 phosphorus in wiregrass 211 days after burning on Leon fine sand in central Florida. Otherwise his findings were similar to those of Davis and Kirk.

The study reported here measured yield, composition, and chemical content of herbage from an ungrazed native range over a 2-year period following a mid-February fire. The study was conducted on the Caloosa Experimental Range in Charlotte County, Florida, on lands owned by the Babcock Florida Company. Chemical analyses were made by Mr. F. E. Knox, Chemist, USDA Agricultural Research Service, Tifton, Georgia.

1/ Davis, K., and Kirk, W. G. Nutritional quality in pastures. Soil Sci. Soc. Fla. Proc. 12. 1952.

2/ Killinger, G. G. Effect of burning and fertilization of wiregrass on pasture establishment. Jour. Amer. Soc. Agron. 40. 1948.

Methods

A 1-acre plot of cutover pine flatwoods occupied by pineland three-awn (Aristida stricta) and other wiregrass-type vegetation was burned February 14, 1957. The soil was Adamsville fine sand, a moderately wet, deep sand of low organic content and natural fertility. Beginning three weeks after the fire, herbage was sampled as shown in table 1. Some unscheduled collections for chemical analyses were made for important forage grasses.

Table 1. --Schedule of vegetation sampling for a 2-year period after burning

Component	Sampling interval		
	3-7-57 to 7-11-57	7-11-57 to 2-11-58	2-11-58 to 2-10-59
	- - - - - Days - - - - -		
Total understory	14	--	--
Aristida stricta	(1/)	2/ 30	90
Other herbaceous understory	(1/)	30	90
Shrubs	14	30	90

1/ This component not sampled for chemical content.

2/ Chemical content analyzed only at 90-day intervals.

At each scheduled sampling time percent species composition was estimated on 20 plots (four blocks of five plots each). Total understory herbage and total shrubs were clipped. In the initial collections, samples of total understory were saved for chemical analyses from each of the four blocks. Thereafter, for understory and throughout the study for shrubs, samples for chemical analyses were drawn from clippings accumulated over all four blocks.

Understory herbage was clipped to a stubble-height of 1 inch. The fanlike leaves (or fronds) of saw-palmetto (Serenoa repens) were clipped at the joint between leaf and petiole. Beginning in December of the first year, dead material was gleaned from plots prior to clipping. Plant material was oven-dried and analyzed for crude protein, ash, ether extract, cellulose, lignin, other carbohydrates (by difference), calcium, and phosphorus. Methods of analysis were those reported by Halls et al. 3/

Yield and Species Composition

Total herbage increased from 66 pounds (moisture free) per acre 3 weeks after burning to a maximum of 3,568 pounds in the fall of the second year (fig. 1). Maximum herbage produced the first year following burning was 2,224 pounds per acre harvested in the late fall. Herbage production declined after November each year.

Pineland three-awn was the first species to recover and was the principal contributor to herbaceous composition throughout the 2-year period of study. This one species comprised 97 percent of the total herbage 3 weeks after burning, 90 percent after 5 weeks, and 73 to 83 percent thereafter (table 2).

3/ Halls, L. K., Hale, O. M., and Knox, F. E. Seasonal variation in grazing use, nutritive content and digestibility of wiregrass forage. Ga. Agr. Expt. Sta. Tech. Bul. (n. s.) 11. 1957.

Burning on the Caloosa Experimental Range for herbage production study.

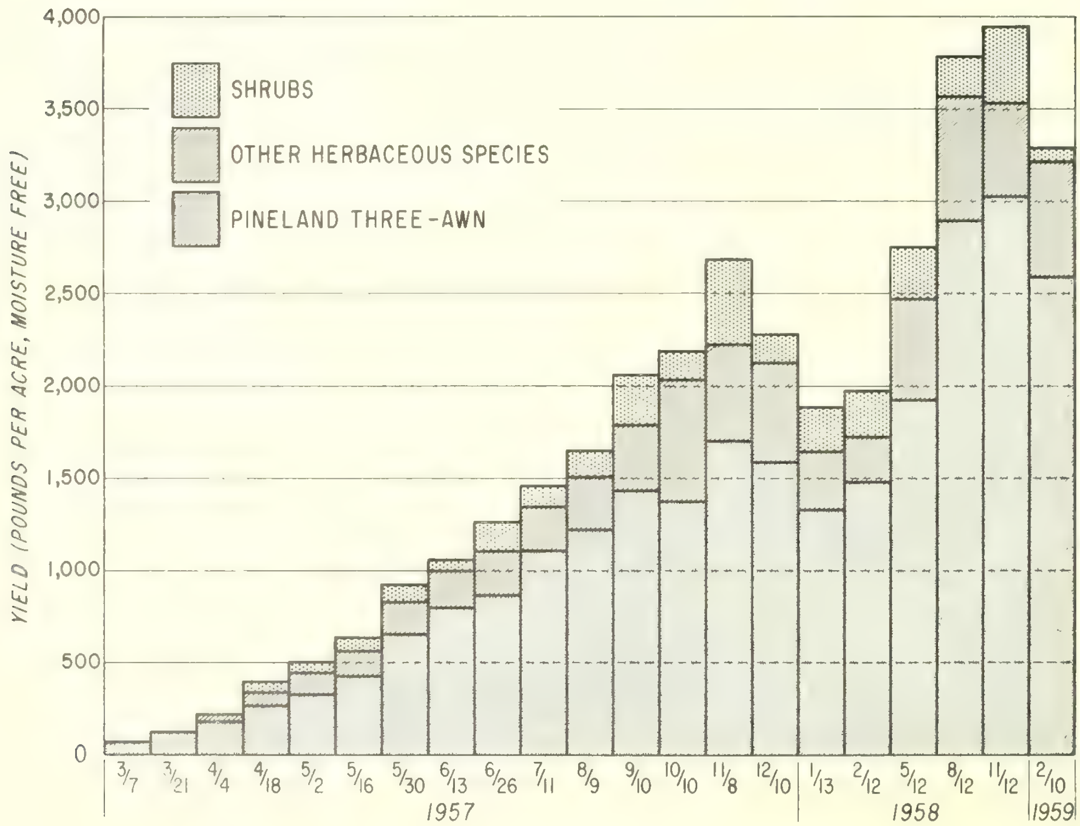

Figure 1. --Yield of pineland three-awn, other herbaceous species, and shrubs on a south Florida range over a 2-year period following a February 14, 1957, fire.

Pineland three-awn, the principal plant in the herbaceous understory on most pine flatwoods ranges in south Florida.

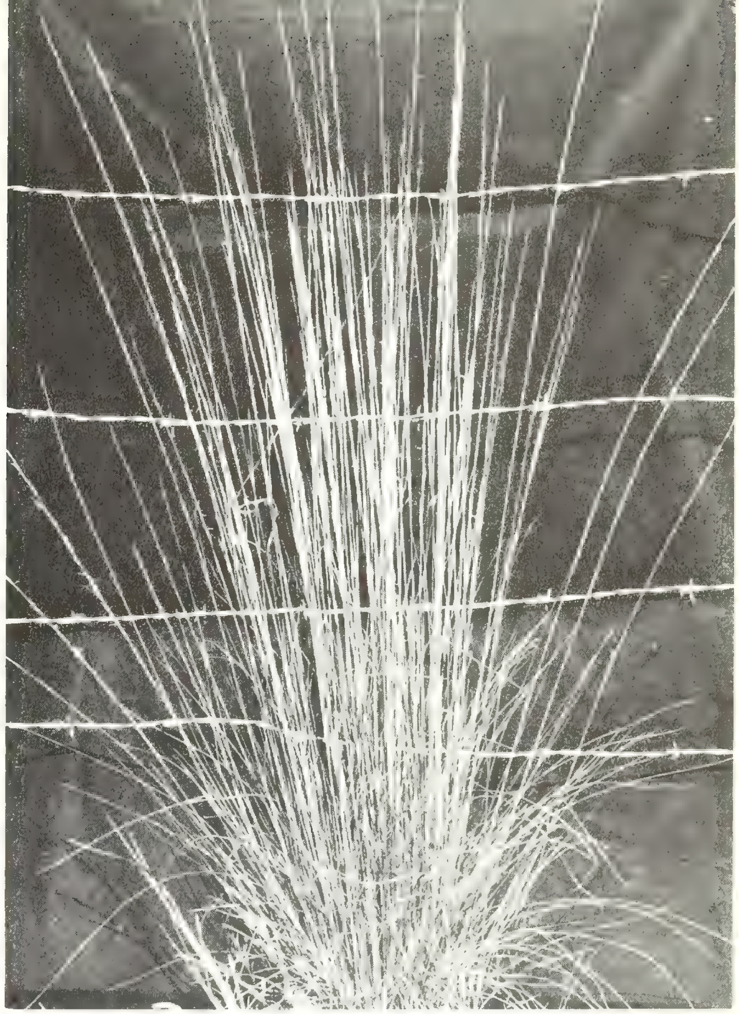

Table 2. --Major components of understory herbage on a south Florida range over a 2-year period following a fire on February 14, 1957

Component	1957								1958		1959
	3-7	3-21	4-4	4-18	5-2	5-16	7-11	11-18	1-13	8-12	2-10
	Percent composition by weight										
Aristida stricta	97	90	83	79	73	75	82	76	81	81	81
Aristida spiciformis										1	1
Andropogon spp.	1	1	1	4	2	2	2	2	2	2	2
Panicum tenerum			1			1	1	2	1	2	1
Panicum chamaelonche				1	1	1					
Other Panicum			1	2	3	2	2	2	2	2	1
Amphicarpum muhlenbergianum			1	1	2	3	1	1	1	1	2
Fuirena scirpoidea	1	4	4	5	4	4	2	3		2	2
Rhynchospora spp.			1	1	2	3	4	4	8	4	4
Scleria spp.			1		1	1	1	3			
Xyris spp.	1	1	2	2	5	4	2	3	4	4	5
Other forbs		4	5	5	7	3	2	4	1	1	1
Other herbage						1	1				
	100	100	100	100	100	100	100	100	100	100	100

Four or five other species, including yellowsedge bluestem (Andropogon virginicus), chalky bluestem (Andropogon capillipes), umbrella grass (Fuirena scirpoidea) and yelloweyed grass (Xyris elliottii), had begun growth 3 weeks after the fire, but these species contributed only 3 percent of total herbage production. From 5 to 11 weeks after the range was burned, a variety of forbs dominated the "other understory." Forbs (other than species of Xyris) then declined and became relatively unimportant.

Six or seven grasses, all palatable to cattle, contributed significantly to the "other understory": goobergrass (Amphicarpum muhlenbergianum), yellowsedge bluestem, chalky bluestem, and three or four panics, including primarily Panicum tenerum and Panicum chamaelonche.

Only one palatable grasslike plant, umbrella grass, contributed materially to the understory. Other grasslikes, predominantly beakrushes (Rhynchospora spp.) and razorsedges (Scleria spp.), increased consistently over the 2-year period. Scleria ciliata increased markedly in the fall of the first year. This plant is grazed by cattle and its seeds are eaten by quail.

Shrub cover was sparse on the study area, and considerable variability in volume was encountered in sampling. Shrubs reached a maximum of slightly over 400 pounds per acre toward the end of the second year. Saw-palmetto and seminoletea pawpaw (Asimina reticulata) were the first shrubs to resprout in measurable amounts; measurable volumes were recorded April 4, seven weeks after burning the range. Saw-palmetto, which comprised 90 percent or more of the shrub volume, was widespread on the study area. Two other shrubs, gallberry (Ilex glabra) and gopherapple (Chrysobalanus oblongifolius), were encountered sparingly.

As pineland three-awn and other wiregrasses mature, yellowsedge bluestem (foreground) assumes a greater part of the grazing load.

Chemical Composition of Herbage

Trends in chemical content generally followed those reported by Davis and Kirk (see footnote 1). Younger herbage emerging after the fire was higher in protein, ash, calcium, and phosphorus, and lower in lignin than more mature herbage (tables 3 and 4). Trends were most noticeable during the first 5 months (fig. 2).

Table 3. --Chemical composition of herbage in the understory vegetation for 2 years after burning on February 14, 1957

Date	Total water	Ash	Crude protein	Ether extract	Cellulose	Lignin	"Other" carbohydrates	Calcium	Phosphorus
	Percent								
				Total understory					
Mar. 7, 1957	75.9	6.12	12.84	1.61	36.31	11.67	31.44	0.10	0.14
Mar. 21, 1957	70.8	7.18	11.63	1.60	34.48	12.99	32.11	.12	.12
Apr. 4, 1957	68.0	7.24	9.55	2.13	34.86	13.13	33.09	.10	.08
Apr. 18, 1957	65.4	5.32	7.87	2.54	35.83	12.86	35.57	.10	.07
May 2, 1957	62.3	4.46	6.82	2.43	35.68	13.62	37.00	.12	.06
May 16, 1957	60.2	4.18	5.44	2.34	35.36	14.13	38.54	.08	.04
May 30, 1957	56.4	3.84	5.02	2.20	37.48	15.88	35.59	.07	.04
June 13, 1957	--	3.64	4.36	2.15	35.78	15.88	38.18	.07	.04
June 27, 1957	54.1	3.56	3.98	2.08	36.27	15.32	38.78	.06	.04
July 11, 1957	50.1	3.80	3.82	2.01	36.56	15.66	38.08	.06	.03
Nov. 8, 1957 1/	58.8	5.17	6.02	1.53	35.22	16.20	35.86	.06	.05
Nov. 8, 1957 2/	60.4	4.87	7.05	1.42	36.40	14.38	35.88	.07	.07
May 30, 1957 3/	63.6	4.82	7.78	2.36	36.00	17.72	31.32	.09	.06
				Aristida stricta 4/					
July 11, 1957	46.2	3.32	3.30	1.88	36.20	15.10	40.20	.06	.03
Nov. 8, 1957	35.6	2.92	2.38	1.89	37.50	16.54	38.77	.05	.01
Feb. 11, 1958	35.9	2.65	2.13	1.47	36.56	16.15	41.04	.05	.01
May 12, 1958	36.7	3.10	2.60	1.40	38.45	16.20	38.25	.07	.02
Aug. 12, 1958	35.9	3.30	2.30	1.50	36.90	16.30	39.70	.05	.02
Nov. 12, 1958	32.1	3.20	2.50	1.50	35.80	15.10	41.90	.06	.02
Feb. 10, 1959	26.2	3.50	2.80	1.40	37.80	16.20	38.30	.06	.01
				Other understory 4/					
July 11, 1957	58.4	4.88	4.90	2.79	35.00	15.70	36.73	.09	.04
Aug. 9, 1957	64.1	5.17	5.08	2.49	35.10	14.92	37.24	.11	.07
Sept. 10, 1957	56.6	5.61	5.61	2.45	33.20	16.00	37.13	.10	.06
Oct. 10, 1957	60.9	4.95	4.84	2.48	35.40	15.98	36.35	.10	.05
Nov. 8, 1957	53.3	2.78	3.34	2.38	35.10	15.92	40.48	.10	.03
Dec. 10, 1957	--	4.63	3.65	1.94	34.00	16.50	39.28	.08	.02
Jan. 13, 1958	--	4.31	3.65	1.73	33.10	18.06	39.15	.09	.02
Feb. 11, 1958	48.0	4.72	3.75	1.87	34.46	17.74	37.46	.13	.02
May 12, 1958	51.3	4.22	4.04	1.80	35.95	19.08	34.91	.09	.03
Aug. 12, 1958	60.3	3.80	3.70	1.90	36.00	18.10	36.50	.09	.02
Nov. 12, 1958	41.1	3.50	3.20	2.00	35.80	16.00	39.50	.09	.02
Feb. 10, 1959	36.5	3.40	3.60	1.80	36.70	16.80	37.70	.13	.01

1/ Regrowth on clipped plots between September 10 and November 8, 1957.
2/ Regrowth on clipped plots between October 10 and November 8, 1957.
3/ Taken from area adjacent to study area that was burned and grazed.
4/ Total understory was divided into Aristida stricta and other understory beginning on July 11, 1957.

Table 4. --Chemical composition of shrubs for 2 years after burning on February 14, 1957

Date	Total water	Ash	Crude protein	Ether extract	Cellu-lose	Lignin	"Other" carbo-hydrates	Calcium	Phos-phorus
	- - - -	- - - -	- - - -	- - - -	Percent	- - - -	- - - -	- - - -	- - - -
				Total shrubs [1]					
Apr. 18, 1957	59.1	4.40	7.72	1.95	33.20	19.68	33.05	0.14	0.09
May 16, 1957	59.0	3.86	7.81	2.44	30.90	21.85	33.14	.22	.09
May 30, 1957	57.9	3.63	7.91	2.00	31.25	23.75	31.46	.19	.08
June 13, 1957	--	3.30	7.69	2.08	30.90	24.65	31.38	.17	.06
				Serenoa repens					
May 2, 1957	57.4	3.80	7.64	1.69	31.60	23.10	32.17	.10	.09
June 27, 1957	56.8	3.03	7.28	2.00	30.86	23.50	33.33	.12	.07
July 11, 1957	56.4	3.23	7.28	2.15	30.32	22.50	34.52	.08	.07
Nov. 8, 1957	52.9	2.63	5.74	1.58	27.60	24.00	38.45	.13	.05
Feb. 11, 1958	52.3	2.64	5.41	1.93	27.75	22.30	39.97	.11	.05
May 12, 1958	45.7	2.70	5.12	1.80	29.00	23.36	38.02	.09	.04
Aug. 12, 1958	53.9	2.70	4.90	2.40	26.20	23.40	40.40	.06	.04
Nov. 12, 1958	39.1	2.50	5.50	2.20	27.80	21.40	40.60	.07	.05
Feb. 10, 1959	53.1	2.80	5.20	1.90	27.80	21.60	40.70	.07	.02

1/ Composed primar.ly of Serenoa repens.

Crude protein content was highest in the new growth of all vegetation, but decreased as the plants matured. Total understory, primarily pineland three-awn, decreased rapidly from 12.84 percent to 3.82 percent crude protein during the 5 months following fire. Other understory increased in crude protein content from July 11 to September 10, 1957. Thereafter, other understory followed the gradual downward trend of pineland three-awn to more or less uniformly low levels. After April 18, shrubs were higher in crude protein than understory herbage.

Young sprouts of understory herbage contained 0.14 percent phosphorus. Content decreased rapidly from this peak to 0.04 percent 3 months after the fire, and remained near or below this low level throughout the 2-year period. Similar trends and levels were found for saw-palmetto. On the 2-year rough none of the groups or species sampled contained more than 0.02 percent phosphorus.

Calcium content of understory herbage fluctuated from 0.10 to 0.12 percent during the 3-month period following burning, declined gradually during the next two months to a level of 0.06 percent, and held at about this low level throughout the next 18 months. Other understory herbage contained higher percentages of calcium than pineland three-awn throughout most of the 2-year period. This component of the vegetation was highest in percent calcium (0.13) in February, both in 1958 and 1959. New growth of shrubs was very high in calcium. Content in saw-palmetto, the principal shrub, decreased during the second year to about the same low level found for pineland three-awn.

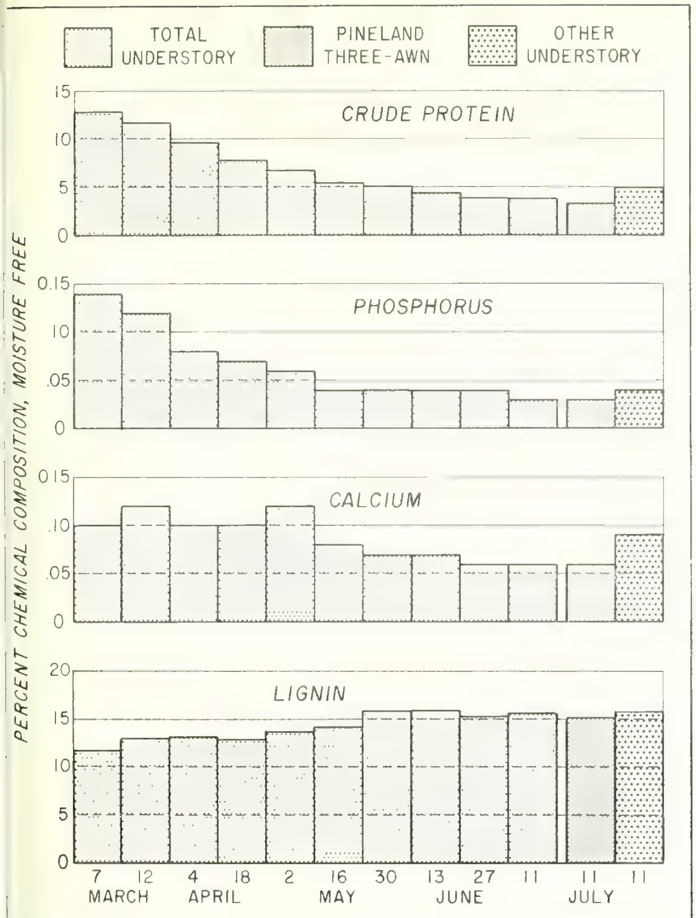

Figure 2. --Percent chemical composition of herbage for 5 months after burning on February 14, 1957.

Lignin for the most part increased rapidly during the first 3 months of vegetative growth. After the initial increase, lignin content remained fairly constant.

The lower portions of buds, or emerging leaves, of saw-palmetto were higher in crude protein and phosphorus, while lower in lignin than the mature fronds (tables 4 and 5). Chalky bluestem, lopside Indiangrass (Sorghastrum secundum), and goobergrass were generally higher in calcium and phosphorus and lower in lignin than total understory. Goobergrass was considerably higher in ash, crude protein, calcium, and phosphorus, while lower in lignin than total understory on the dates the additional species were sampled.

Leaves of saw-palmettoes growing on a nearby Keri fine sand with underlying marl contained 0.29 percent calcium (table 5). Palmettoes in this area had been grazed heavily by cattle. No notable differences between upper and lower portions of saw-palmetto leaves were found on this site.

Seasonal trends in chemical content of herbage growing on the experimental area were not conspicuous. Other carbohydrates in other understory herbage were slightly higher than average in the fall and slightly lower than average in the late spring.

Table 5.--Chemical composition of supplemental samples of grasses and individual portions of saw-palmetto

Date	Total water	Ash	Crude protein	Ether extract	Cellulose	Lignin	"Other" carbohydrates	Calcium	Phosphorus
	Percent								
				Andropogon capillipes					
May 16, 1957	61.2	3.76	5.94	3.49	32.10	13.50	41.21	0.09	0.06
				Amphicarpum muhlenbergianum					
Apr. 18, 1957	72.1	10.25	11.70	3.71	29.70	7.03	37.61	.14	.08
				Sorghastrum secundum					
Apr. 12, 1957	62.2	6.48	6.20	2.01	36.00	11.52	37.79	.14	.07
				Serenoa repens					
Feb. 12, 1958 1/	59.1	3.60	5.36	1.85	31.90	22.72	34.57	.13	.09
Feb. 12, 1958 2/	74.2	4.68	7.57	1.69	34.10	18.00	35.96	.11	.13
Feb. 11, 1959 3/	--	3.50	7.30	1.90	24.10	25.10	38.10	.29	.05
Feb. 11, 1959 4/	--	3.30	6.70	1.60	26.50	24.40	37.50	.29	.05

1/ Upper portion of buds on the study area.
2/ Lower portion of buds on the study area.
3/ Upper portion of fronds on Keri fine sand underlain by marl.
4/ Lower portion of fronds on Keri fine sand underlain by marl.

Discussion

Herbage on south Florida ranges emerged rapidly after burning in February. Growth during the first 3 weeks was 66 pounds per acre, or an average of 3.1 pounds per acre per day. This increased to 19.0 pounds per acre per day for the 2-week period ending May 30, 1957. Thereafter, growth slowed to average about 4 pounds per acre per day over the 2-year period.

While occasional subnormal weather in the winter or inundation of vegetation during the summer greatly curtailed plant growth, some growth continued most of the year. Beginning in late November and continuing until mid-January, herbage deterioration exceeded growth, and the total volume of herbage declined. December 1957 was abnormally cold; for example, the temperature dropped to 27° F. on December 12 and 13, 1957.

Pineland three-awn, through its ability to resprout rapidly after burning, maintains dominance in the understory on south Florida ranges. During the first 2 or 3 months on recent burns, this species is the primary component of cattle diet. As pineland three-awn matures, a greater proportion of the other plants are consumed.

Although herbage yield was low on recent burns, nutritive quality was higher than any other time during the 2 years. Nine to 11 weeks following the fire, crude protein had decreased to inadequate levels for cattle maintenance (National Research Council 4/).

4/ National Research Council. Nutrient requirements of domestic animals. No. 4: Nutrient requirements of beef cattle. Natl. Acad. Sci. Pub. 579. 1958.

Chemical analyses of herbage from adjacent grazed range indicated that grazing may delay a rapid drop in protein. The level of protein in grazed herbage collected on May 30, 1957, was about the same as in ungrazed herbage collected six weeks earlier (table 2).

Phosphorus--borderline for proper animal nutrition 3 weeks after burning--was deficient in all subsequent samplings. In no case did calcium meet minimum requirements for cattle maintenance. Most ranchers feed mineral supplements high in phosphorus and calcium year-round to cattle on native range.

Shrubs, especially saw-palmetto, are more abundant on many south Florida ranges than data from this study would indicate. Leaves of saw-palmetto emerging on recently burned ranges are grazed by cattle, and mature fronds are occasionally cropped heavily when a sufficient variety or volume of forage is not available. Unfolding leaves were higher in crude protein and phosphorus, but lower in lignin, than mature fronds. Although shrubs generally contained more crude protein, calcium, and phosphorus than understory vegetation, their lignin content was also higher. Consequently, the nutrients in saw-palmetto and other woody growth were probably less available. On some sites where marl is near the soil surface, cattle may heavily graze palmettoes because of the higher-than-average calcium content.

Heavy grazing (foreground) delays the rapid drop in protein in recently burned herbage.

Summary

Livestock ranges in south Florida are burned during the winter season every 2 or 3 years to remove old growth and provide cattle with readily available new growth. A study on the Caloosa Experimental Range, Charlotte County, Florida, measured yield, composition, and chemical content of herbage from ungrazed native range during a 2-year period following burning on February 14, 1957.

Production of herbage increased rapidly following burning. Yields were 66 pounds per acre at 3 weeks and 2,200 pounds per acre at 9 months. The highest accumulative production, approximately 3,500 pounds per acre, was attained in November of the second year. Shrubs were relatively unimportant on the study area.

Pineland three-awn was the principal plant in the herbaceous understory. It comprised 95 percent of the total herbage 3 weeks after burning and thereafter averaged 75 to 80 percent. A variety of other grasses, grasslikes, and forbs contributed to total herbage. Saw-palmetto was the principal shrub on the study area and comprised 90 percent or more of browse volume.

Nutrient levels of herbage were generally highest in the young growth immediately after burning. Crude protein in pineland three-awn and other herbage decreased rapidly to amounts inadequate for cattle; calcium and phosphorus were always inadequate. Mineral supplement affords an effective means of offsetting nutrient decline and enables ranchers to make use of the large volumes of feed produced on native ranges. Other management tools for maintaining or improving forage quality--such as progressive burning over the winter season and additions of low-cost rock phosphate--merit further research attention.

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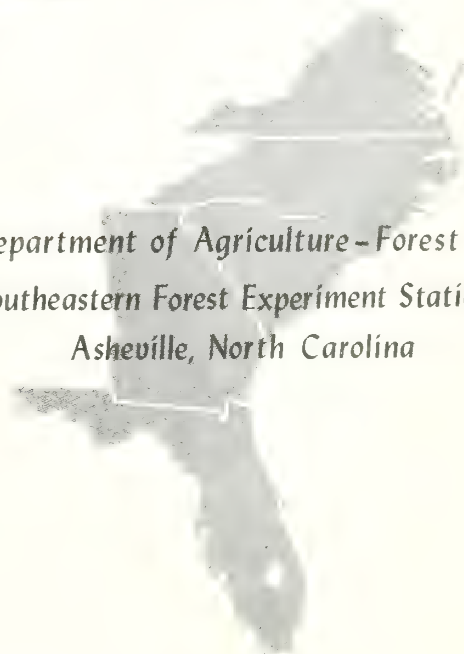
Seasonal Moisture Fluctuations in Four Species of Pocosin Vegetation

by

George W. Wendel

and

Theodore G. Storey



U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Seasonal Moisture Fluctuations in Four Species of Pocosin Vegetation

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INTRODUCTION

During the most severe burning conditions practically all of the living understory vegetation on pocosins may be consumed by fire (9). Even under less severe conditions leaves and branch tips are readily consumed. Whether the moisture content in the living vegetation is high, as it is in the spring, or low, as in the winter, exerts a strong influence on fuel flammability and fire behavior. The moisture content in live pocosin fuels is generally higher than in dead fuels; however, the moisture content of individual plant species and the seasonal moisture changes are not known. This paper reports on the moisture content fluctuations for one year in four common understory plants in North Carolina pocosins: common gallberry (*Ilex glabra*), redbay (*Persea borbonia* (L.) Spreng.), swamp cyrilla (*Cyrilla racemiflora* L.), and switch cane (*Arundinaria tecta* (Walt.) Muhl.) (figures 1 to 4).

The primary purpose of this study was to determine the time of occurrence and magnitude of the yearly extremes in moisture content in these species and the patterns of seasonal change. A secondary purpose was to ascertain if moisture content in common gallberry growing on a mineral soil differed from moisture content in common gallberry growing on an organic soil. No attempt was made to correlate the results of this study with specific fire behavior patterns because the relations are not well understood.

Limited studies with other species in the Pacific Northwest (5) and northern Rocky Mountains (7) have shown that the moisture content in various shrubs and grasses decreased during the normal summer fire season. Reifsnyder (6) reported that the lowest moisture content in the older leaves of mountain laurel (*Kalmia latifolia* L.) in Connecticut occurred in the spring and fall, the normal fire seasons in the area. In general, moisture content in living and dead fuels is inversely proportional to the rate of fire spread (1, 2, 4) and, therefore, the extent of curing in green fuels should be considered in any system for rating forest fire danger (3).

Figure 1.--Common gallberry.

Figure 2.--Redbay.

Figure 3.--Swamp cyrilla.

Figure 4.--Switch cane.

THE STUDY AREA

All sampling was done on Hofmann Forest in Jones and Onslow Counties, North Carolina. The organic soil sampling areas are characterized by wet, poorly-drained mucky peat soils, 1 to 3 feet deep, with an organic matter content of 25 to 90 percent. The overstory is a low-density pond pine (*Pinus serotina* Michx.) stand with a dense switch cane or shrub understory. The mineral soil is a fairly well-drained sandy loam with an open, switch cane-shrub understory and an overstory of scattered pond pine (table 1).

Ground water level, precipitation, and temperature records were obtained from the Maysville weather station, approximately $3\frac{1}{2}$ miles from the sampling areas. Staff gage readings taken intermittently in soil auger holes in the sampling areas showed the same trends as the well recorder data.

Monthly precipitation during the study was near or above the 9-year average, except for May and June, which were 1.90 inches and 2.75 inches, respectively, below the average (fig. 5) (8).

Maximum and minimum temperatures were about normal during the course of the study.

A prolonged dry period occurred between April 12 and June 28; during this time the maximum depth to the water table was 4 feet. The water table did not drop below 3 feet for any extended period during the remainder of the year.

SAMPLING PROCEDURE

Five whole plant[1/] samples of each species were collected at weekly intervals during the first 9 months. Sampling was intermittent for the remainder of the year and varied from 1 to 3 weeks between samplings. Samples of each species were collected at nearly the same time each sampling day to minimize the effects of diurnal variation in moisture content. Criteria for selecting each sample plant were height and crown form (table 1).

The foliage was separated from the woody parts and the moisture contents, based on ovendry weight of each component and for the whole plant, were determined.

1/ Above-ground portion, exclusive of roots.

Table 1.--Descriptions of species and sampling sites

Species	Criteria for selecting sample bushes	Site
Common gallberry (*Ilex glabra*)	Bushes 3.5 to 4.0 feet tall, generally clump grown. Stems usually clear for 2.5 feet, symmetrical crowns.	Mineral soil, with humus layer $1\frac{1}{2}$ inches deep underlain by fine sand. Fair internal drainage.
		Organic soil, 2 to 3 feet deep peaty muck, mineral content 10 percent. Poorly drained.
Redbay (*Persea borbonia* (L.) Spreng.)	Shrubs 3.5 to 4.0 feet tall, 2- to 3-year-old sprouts. Stem diameter at ground level $\frac{1}{2}$ inch.	Organic soil. Same site as common gallberry.
Swamp cyrilla (*Cyrilla racemiflora* L.)	Shrubs 4.0 to 5.0 feet tall, single stems finely branched at top, symmetrical crowns.	Organic soil, similar to that for redbay.
Switch cane (*Arundinaria tecta* (Walt.) Muhl.)	At least 2-year-old canes, 4.0 to 5.0 feet tall, growing in a medium density cane brake.	Organic soil, 8 to 12 inches deep. 25 percent organic matter by loss on ignition.

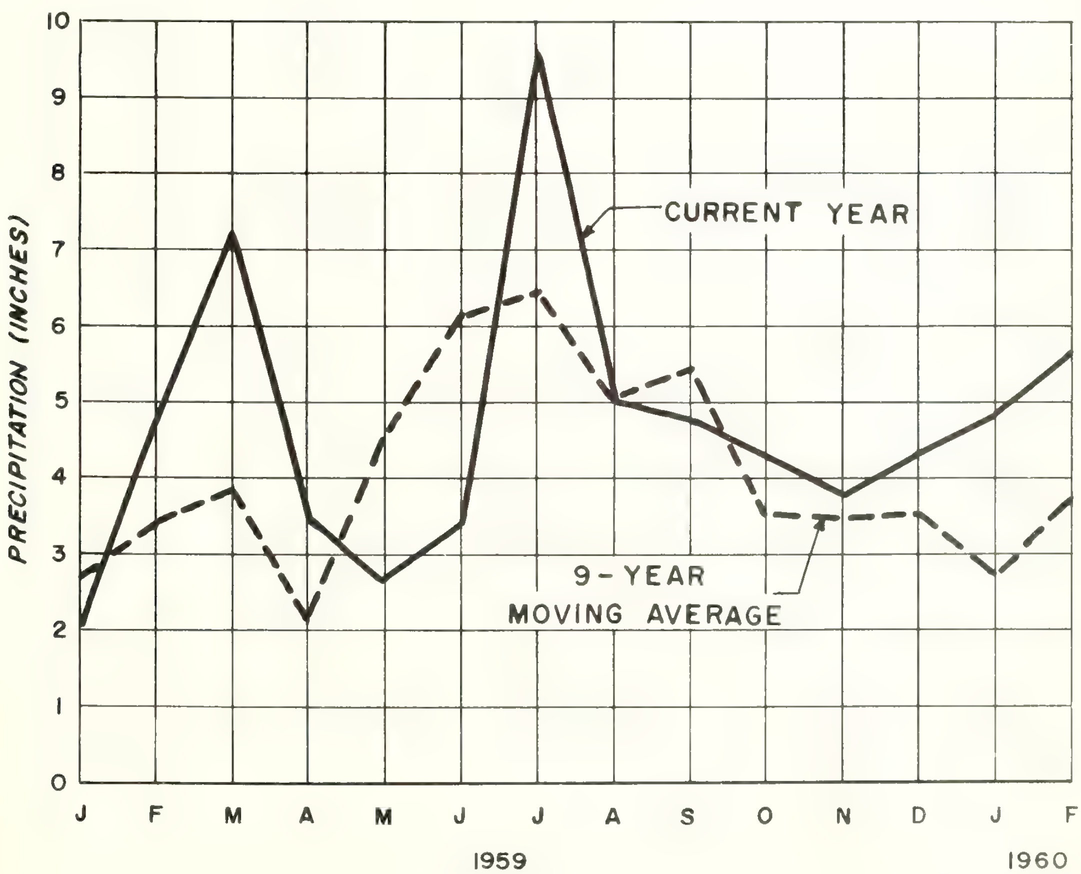

Figure 5.--Comparison of monthly precipitation during the study period and the 9-year moving average (1951-1960), recorded at the Maysville, North Carolina, weather station.

MOISTURE CONTENT FLUCTUATIONS

Whole plant moisture content in all species except common gallberry on both sites increased gradually from the end of March until a maximum was reached in late May and early June (fig. 6). The moisture content increase in common gallberry began in early May, with the maximum occurring in June on the dry site and in July on the wet site. A gradual decrease in moisture content occurred during the rest of the year in all species. By January 1960 the whole plant moisture contents had reached levels similar to those of February 1959. Yearly trends were statistically highly significant for all species.

Foliage and stem moisture content for all species followed the same pattern as the whole plant except that foliage moisture contents invariably were higher and stem moisture contents lower.

SITE EFFECTS

An analysis of variance showed a highly significant difference in whole plant moisture content between sites and with time for common gallberry growing on the mineral soil and on the organic soil (table 2). The significant interaction of site with time indicates that the moisture content of common gallberry on the two sites did not follow the same general pattern in the spring and early summer as in the late summer and fall (fig. 6).

DISCUSSION

The moisture content in the foliage, stems, and whole plants varied widely within and between species with time. The moisture content in cyrilla foliage ranged from a high of 322 percent to 104 percent, in switch cane from 190 percent to 54 percent, in gallberry from 143 percent to 96 percent, and in redbay from 138 percent to 56 percent. Redbay and common gallberry are evergreen shrubs, swamp cyrilla is practically deciduous, and switch cane leaves die in the winter but remain on the canes until spring. These leafing characteristics probably account, in part, for the wide ranges in foliage moisture content.

During a 10-week drought period in the spring, the moisture content in all species continued to rise. Except for a slight recharging of the water table in May, a general fall in the water table was recorded from April 12 to June 28. Evidently the low water table did not reduce soil moisture enough to affect plant moisture content.

Figure 6.--Seasonal trend in moisture content in whole plant, stems, and foliage of four species of pocosin vegetation, Hofmann Forest, North Carolina. Each point is the average of five samples.

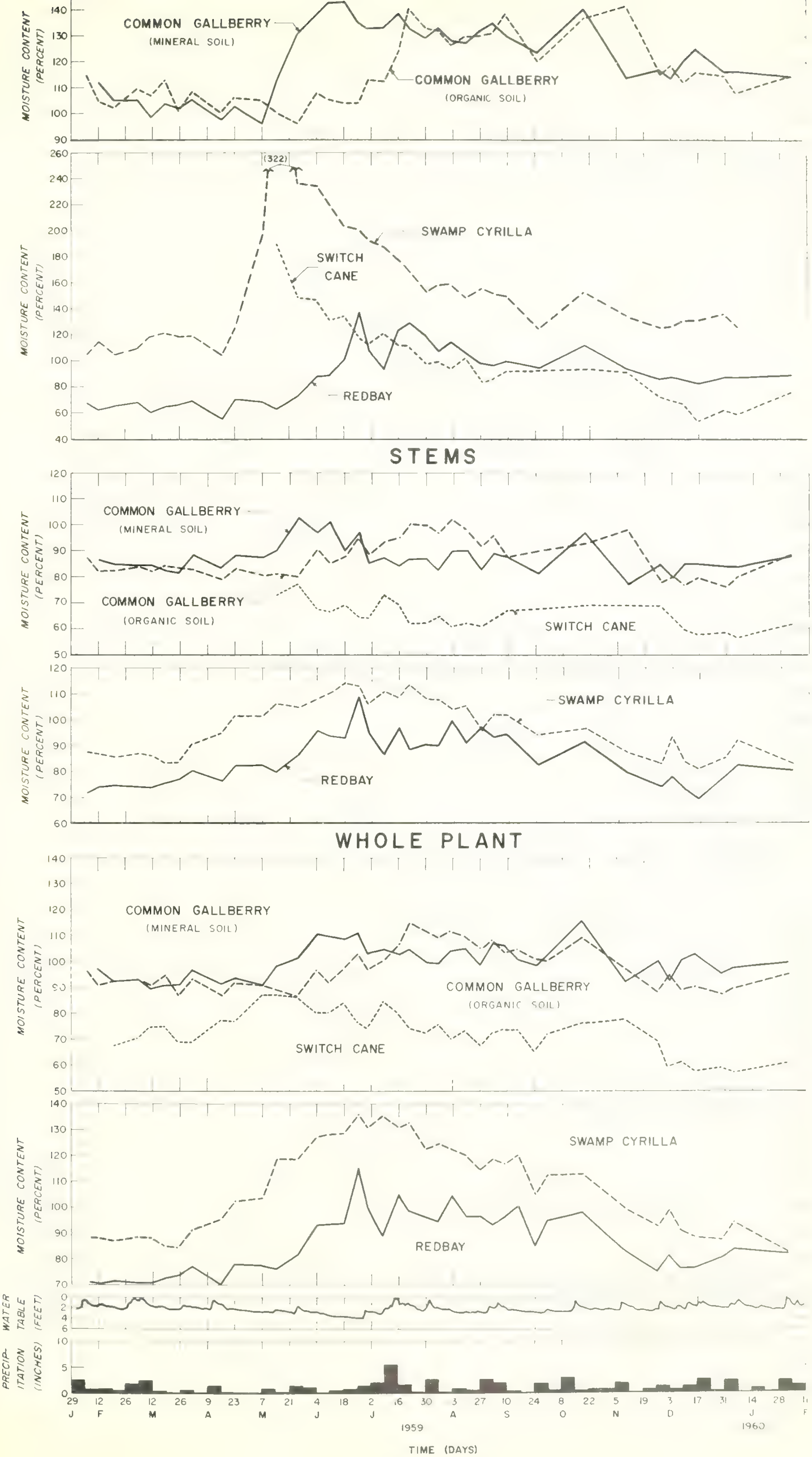
COMMON GALLBERRY (MINERAL SOIL)
COMMON GALLBERRY (ORGANIC SOIL)
MOISTURE CONTENT (PERCENT)
(322)
SWAMP CYRILLA
SWITCH CANE
REDBAY
STEMS
WHOLE PLANT
WATER TABLE (FEET)
PRECIPITATION (INCHES)
29 12 26 12 26 9 23 7 21 4 18 2 16 30 3 27 10 24 8 22 5 19 3 17 31 14 28 11
J F M A M J J A S O N D J F
1959
1960
TIME (DAYS)

Table 2.--Analysis of variance, moisture content of whole plant common gallberry growing on a mineral soil and on an organic soil

Source of variation	Degrees of freedom	Sum of squares	Mean square
Site	1	620.9	13.43**
Time	37	16,629.1	9.72**
Site x Time	37	6,030.8	3.53**
Error	304	14,047.8	
Total	379	37,328.6	

** Highly significant, 1 percent level.

There is some evidence to suggest that the significantly higher moisture content in whole plants of common gallberry on the dry site in the spring and summer may not be characteristic. A freeze on May 16 partially killed much of the new growth on the wet-site gallberry, thus reducing the total foliage moisture content. Common gallberry on the dry site was not affected by the freeze.

During 1959 the lowest moisture content in the four species occurred in the spring and late fall, also the seasons of greatest fire occurrence in eastern North Carolina.

SUMMARY

The moisture content fluctuations in the foliage, stems, and whole plants of common gallberry, redbay, swamp cyrilla, and switch cane growing on an organic soil pocosin were determined for one year, as well as the moisture content in common gallberry growing on a mineral soil.

Statistical tests revealed highly significant differences in moisture content with time for all species. The moisture content in common gallberry on the organic site was significantly greater than that on the mineral site. This difference may have been caused by a reduction in new growth on the organic site as a result of a freeze in May.

A continuous fall in the water table during a 10-week period in the spring did not bring on a decrease in whole plant moisture content.

The periods of lowest vegetation moisture content coincided with the seasons of greatest fire occurrence in eastern North Carolina.

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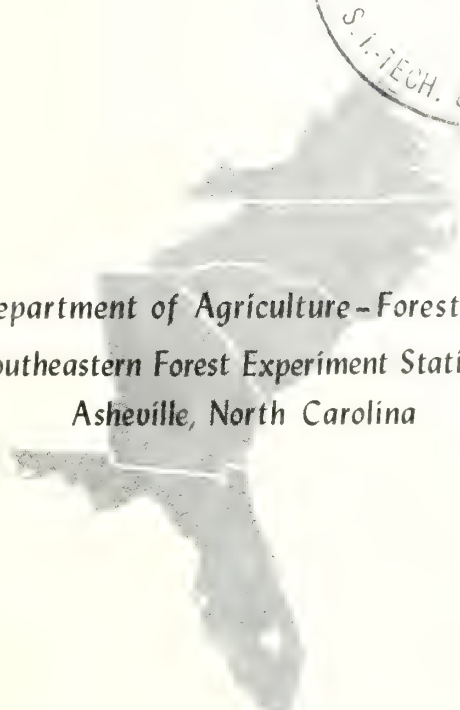
August 1962

Fertilization of Young Slash Pine in a Cultivated Plantation

by

Ralph H. Hughes and James E. Jackson



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Fertilization of Young Slash Pine in a Cultivated Plantation

by

Ralph H. Hughes and James E. Jackson[1/]

Observations in the southern pinelands have shown that serious damage to plantations by cattle browsing and trampling is limited to trees less than 6 to 8 feet tall, except where cattle are concentrated (Cassady, Hopkins, and Whitaker, 1955). The possibility that application of fertilizer with clean cultivation would increase growth rate, producing a 6- to 8-foot tree in 3 or 4 years, plus the need to know more about growth response of slash pine (Pinus elliottii Engelm. var. elliottii), prompted this study to test the effect of several kinds, rates, and combinations of inorganic fertilizers.[2/]

METHODS

A longleaf-slash pine stand, with an understory of "wiregrass" and gallberry, located near Alapaha, Georgia, was selected for the study. The soil was Lynchburg loamy sand, imperfectly drained and of low fertility. The site was cleared, stumped, and thoroughly worked with a tandem disk-harrow. Grade 1 slash pine seedlings were planted at a spacing of 10 x 10 feet over the entire area. Soil analyses showed 28 pounds available P_2O_5, as determined by the modified Truog method using colorimetry, 30 pounds available K_2O, and 400 pounds available CaO per acre.

1/ Respectively, Range Conservationist, Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, and formerly Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture.

2/ Cooperative investigations of the Forest Service and Agricultural Research Service of the U. S. Department of Agriculture, and the University of Georgia College of Agriculture Experiment Stations, Coastal Plain Experiment Station, Tifton, Georgia. Published with the approval of the Director as Journal Series Paper No. 95.

The study consisted of a factorial test and three accessory phases totaling 42 treatments, replicated three times, each employing nitrogen, phosphorus, and potassium, as follows:

1. A 3 x 3 x 3 factorial experiment (27 treatments) with three rates of nitrogen of 0, 100, and 200 pounds per acre, and phosphorus and potassium at rates equivalent to 0, 50, and 100 pounds of P_2O_5 and K_2O per acre applied to the surface of the soil.

2. Three surface treatments involving minor elements, with two treatments using 200 pounds of nitrogen per acre and one of 400 pounds, each mixed with phosphorus and potassium to equal a 2-1-1 (N-P_2O_5-K_2O) ratio. One of the 200-pound nitrogen mixtures was combined with the equivalent of 2,000 pounds per acre of dolomitic limestone, the other two treatments (200 and 400 pounds) were combined with 70 pounds of MgO per acre. All three treatments were supplemented with the equivalent of 25 pounds per acre of a minor element mixture containing manganese, zinc, molybdenum, boron, and iron.

3. Ten treatments (eight new treatments, plus two from the 3 x 3 x 3 factorial, the 100-50-50 and 200-100-100 N-P_2O_5-K_2O rates) involving split surface application of fertilizer of 50, 100, 200, 400, and 600 pounds of nitrogen per acre in a 2-1-1 ratio with one-half applied in February or March and one-half in June.

4. Two treatments of a single subsurface application of 100 and 200 pounds of nitrogen per acre in a 2-1-1 ratio placed 4 to 6 inches below the soil surface.

The area was divided into three blocks of 40 plots, each plot containing 16 trees. The 40 treatments were assigned at random within blocks. (Note that 2 of these treatments were common to the factorial test and one accessory phase.)

In all treatments nitrogen was supplied by ammonium nitrate, phosphorus by 20 percent superphosphate, and potassium by 60 percent muriate of potash. Fertilizer materials were broadcast by hand in a 2-foot radius around trees in February 1957, and in a 4-foot radius in March 1958. Trees were not fertilized in 1959 or 1960. The entire area was cultivated as needed with a tandem disk-harrow to control weeds, with occasional hand weeding close to the seedlings.

Measurements were confined to the center square or four trees in each plot, leaving the outer row on each side for isolation from adjacent plots. Heights of trees were measured at the close of the growing seasons in 1957, 1958, 1959, and 1960. Diameters, 6 inches above the ground line, were measured in October 1960. Survival of nearly 100 percent was obtained by planting three seedlings in a hill initially and thinning to one per hill follow-

ing the first flush of growth. Of the 480 plot trees, 17 were cut off in cultivation the first year. These were replaced the first winter by adjoining border trees of approximately the same size.

In 1958, a small adjoining plantation was established to test further some of the most promising treatments of the main study. Treatments were N-P_2O_5-K_2O at rates of 100-50-50, 0-50-0, and 0-0-0 pounds per acre, with care taken to duplicate methods of the main experiment.

RESULTS

Analyses of variance in the factorial experiment of total height of trees at the end of the growing season and of annual increase in tree height revealed consistent similarity between the two measures when related to the main variables and their interactions (table 1). Hence, the two measures apparently provided an equally objective test of fertilizer effects.

Rates and Ratios of Nutrients

First- and second-year results of the factorial were highlighted by two important trends:

1. A highly significant positive response to phosphorus.

2. A significant NxK interaction in which nitrogen without potassium and potassium without nitrogen retarded growth.

Table 1.--Analyses of variance for total height and annual height growth of slash pine in the N-P-K factorial experiment during the first, second, and third years after planting

Observation	Source of variation	D. F.	Mean squares		
			First year	Second year	Third year
Total height	Replication	2	--	--	--
	Nitrogen (N)	2	76.01	376.20	961.72**
	Phosphate (P)	2	534.45**	2,757.25**	4,707.49**
	Potash (K)	2	19.10	118.91	202.28
	N x P	4	5.03	29.37	135.26
	N x K	4	49.26*	190.51*	149.16
	P x K	4	4.97	31.72	89.46
	N x P x K	8	3.37	17.72	85.11
	Error	52	14.10	57.31	115.15
Annual height growth	Replication	2	--	--	--
	Nitrogen (N)	2	47.24	158.97	152.10*
	Phosphate (P)	2	520.36**	905.43**	252.76**
	Potash (K)	2	14.46	54.05	20.55
	N x P	4	3.94	10.18	64.77
	N x K	4	40.70*	59.24*	39.29
	P x K	4	3.83	18.66	40.54
	N x P x K	8	1.60	12.24	35.07
	Error	52	11.36	22.98	40.60

* Significant at 5 percent level.
** Significant at 1 percent level.

Although trees were not fertilized after the second year, the positive response to phosphorus persisted to the end of the fourth growing season, when final measurements were taken. The main effect of nitrogen, obscured by the NxK interaction during the first two years, emerged as an important factor during the third year.

Phosphorus was the most consistently significant and had more effect than other components included in the study. Trees in the N-P-K factorial given phosphorus at the rate of 50 pounds of P_2O_5 per acre in mixed fertilizers attained a height of 27.2 inches in 1 year, 68.6 inches in 2 years, and 115.5 inches in 3 years (fig. 1). Phosphate alone at the 50-pound rate produced trees 1, 2, and 3 years from planting that measured 28.7, 72.7, and 120.6 inches in height (fig. 2). Comparable heights for check trees not fertilized were 22.5, 60.8, and 108.2 (fig. 3). The 100-pound rate of phosphate applied singly or in combination with nitrogen and potash did not stimulate additional growth beyond that resulting from the 50-pound phosphate application. Hence, phosphate alone at the 50-pound rate was the most effective fertilizer tested.

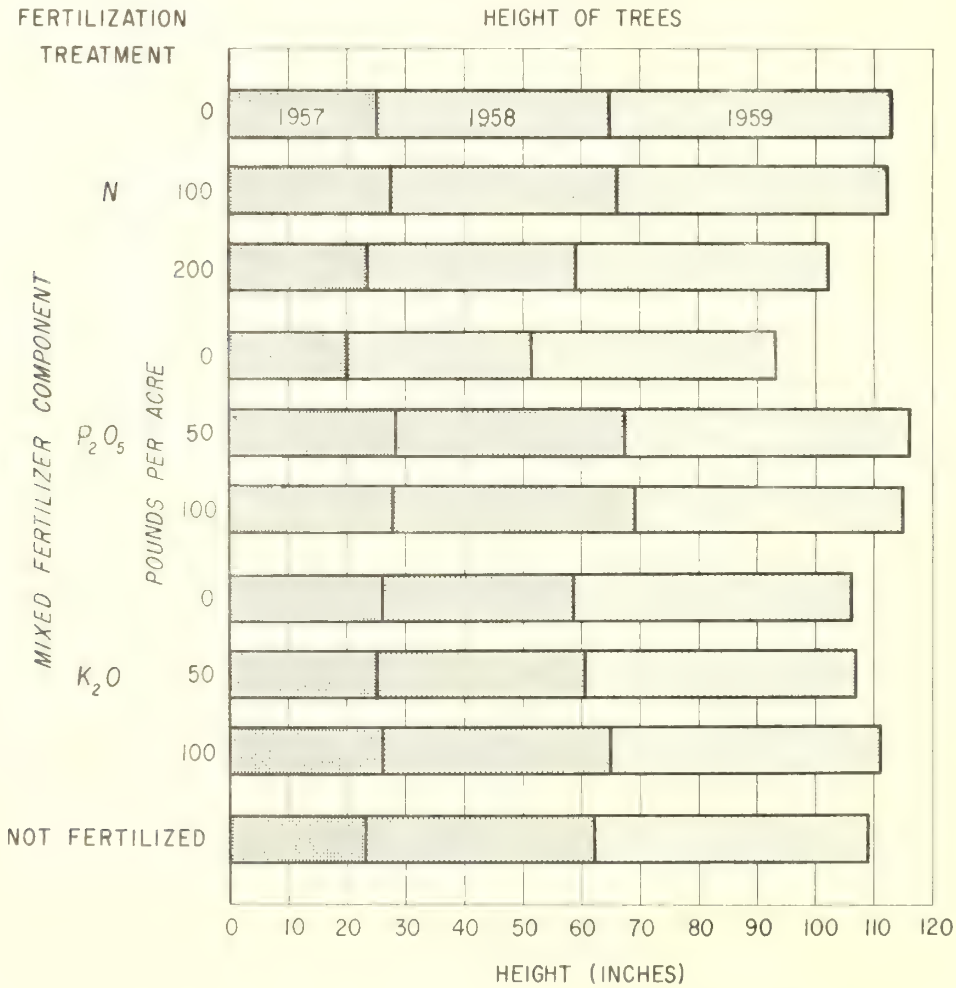

Figure 1.--Average effect of N, P_2O_5 and K_2O mixed fertilizers broadcast around trees February 1957 and March 1958 on height of slash pine planted January 1957. Trees were not fertilized in 1959.

Figure 2. --Seedlings (1-0 stock) annually fertilized with phosphate alone at the rate of 50 pounds per acre reached a height of 72.7 inches in two years.

Figure 3. --Seedlings in plots that were cultivated but not fertilized attained a height of 60.8 inches in two years.

Mixtures lacking phosphorus did not stimulate growth. These trees had average heights of only 19.4 inches the first year, 51.0 inches the second year, and 92.3 inches the third year. In Florida, Barnes and Ralston (1953) observed a similar increase in height growth of young slash pine following heavy application of colloidal phosphate at planting time.

By the end of the fourth growing season, trees given mixed fertilizer containing 50 pounds of phosphate measured 4.50 inches in diameter at stump height (table 2). Trees in plots that received no phosphate averaged only 3.83 inches.

Table 2.--Average diameter[1/] of slash pine in relation to mixed fertilizer component, October 27, 1960 (end of fourth year)

Component	Rate [2/] 0	1	2	Least significant difference (5 percent)
	- - Diameter in inches - -			
N	4.35	4.45	4.12	0.15
P_2O_5	3.83	4.50	4.60	0.15
K_2O	4.22	4.30	4.40	0.15

1/ Measured 6 inches above ground line with diameter tape.
2/ A 3 x 3 x 3 factorial with N at 0, 100, and 200 pounds per acre, and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

Nitrogen alone at the 200-pound rate resulted in a highly significant depression in growth. Stunting was more severe the second year than the first, and persisted through the fourth growing season. When surveyed October 27, 1960 (end of fourth year), these trees measured only 3.17 inches in diameter and 119.2 inches in height in contrast to 4.07 inches in diameter and 158.2 inches high for trees not fertilized. By the third year, nitrogen at the 200-pound rate in mixed fertilizer had emerged as a depressing factor on height, when compared with nitrogen at the 100-pound rate.

Potash in mixtures with nitrogen at the 100-pound rate (averaged for all levels of phosphorus) produced significantly taller trees than most other combinations by November of the first year (table 3). Height with average P_2O_5 and N and K_2O at 100 pounds was 28.6 inches by the end of the first growing season. On the other hand, addition of potash without nitrogen and application of nitrogen without potash reduced tree height, thus accounting for a significant NxK interaction. A sharp reduction in height accompanied increasing amounts of nitrogen without potash, and the same with respect to potash without nitrogen. This effect was not so pronounced the second growing season and, as noted previously, by the end of the third year had lost its significance. Average response to potash was not significant.

Minor Elements

Minor elements, with lime or magnesium added to heavy application of N-P-K mixed fertilizers, did not significantly increase tree growth.

Table 3.--Height of trees in relation to potash and nitrogen (averaged with $P_0 + P_1 + P_2$) broadcast around seedlings in February 1957 and March 1958 1/

Item	N_0	N_1	N_2	Average
HEIGHT OF TREES NOVEMBER 18, 1957 2/				
	- - - - - - Inches - - - - - -			
K_0	26.4	24.8	20.6	23.9
K_1	24.0	25.4	23.1	24.1
K_2	22.6	28.6	25.1	25.5
Average	24.3	26.3	22.9	24.5
HEIGHT OF TREES NOVEMBER 7, 1958 3/				
K_0	67.3	63.7	51.3	60.7
K_1	63.3	63.9	59.9	62.4
K_2	62.5	68.2	64.0	64.9
Average	64.4	65.3	58.4	62.7
HEIGHT OF TREES NOVEMBER 23, 1959 4/				
K_0	113.9	108.8	94.1	105.6
K_1	107.1	109.4	102.7	106.4
K_2	112.5	113.3	105.2	110.7
Average	111.2	110.5	100.7	107.6

1/ A 3 x 3 x 3 factorial with N at 0, 100, and 200 pounds per acre; and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

2/ Least significant difference (5 percent) for average N = 2.1; for K = 2.1; and for interaction (NxK) = 3.6 inches.

3/ Least significant difference (5 percent) for average N = 4.1; for K = 4.1; and for interaction (NxK) = 7.2 inches.

4/ Least significant difference (5 percent) for average N = 5.9; for K = 5.9; and for interaction (NxK) = 10.1 inches.

Although these trees grew rapidly and displayed high vigor, supplements to N-P-K mixtures did not appear essential (table 4). Depression of height growth, as evidenced by heavy applications in the N-P-K factorial test, seemed to be caused by an excess of nitrogen or potassium in the absence of phosphorus and not to deficiencies of minor elements, lime, or magnesium.

Split Application

Split application of fertilizer was no better than single application, although five widely varying rates were tested (table 5). Trees given a split application, one-half broadcast around trees in February or March and one-half in June, averaged about the same size as those given a single application. By the end of the fourth growing season, however, trees given split applications at the minimum rate (50-25-25 pounds of N-P_2O_5-K_2O) measured 4.70 inches in diameter at stump height and trees in the unfertilized check plots measured only 4.07 inches. Trees given the minimum rate in a single application measured 4.33 inches. These results suggest a need for testing split and single applications of fertilizer materials at lower rates than those tried in this experiment.

Subsurface Application

Spot placement of fertilizer 4 to 6 inches below the ground surface resulted in rapid growth of trees equal to surface application (table 6), and in contrast to surface application, discouraged growth of weeds. Though native pine-wiregrass vegetation had previously occupied the site, surface application of fertilizer (other than phosphate alone) encouraged rapid invasion of weeds. An ocular estimate in May 1958 of weed growth on areas around trees fertilized in March indicated an average of $2\frac{1}{2}$ times more annual herbage with broadcast application than with subsurface application of fertilizer. Prompt cultivation was required to prevent crabgrass (Digitaria spp.) and other annual grasses and weeds from forming a sod.

Table 4.--Size of trees in relation to minor elements with lime or magnesium added to heavy applications of N-P-K mixed fertilizers[1/]

Treatment				Height of trees			Diameter
N	P_2O_5	K_2O	Supplement	1957	1958	1959	1960
- - Pounds - -			Kind	- - - - - - - - Inches - - - - - - - -			
200	100	100	Check	26.8	62.7	113.8	4.60
200	100	100	Minor elements and magnesium	26.2	66.4	112.4	4.70
200	100	100	Minor elements and lime	29.6	71.2	115.8	4.73
400	200	200	Minor elements and magnesium	27.8	69.4	114.1	4.60

1/ See page 2 for list of minor elements.

Table 5.--Size of trees with split application and single application of N-P-K mixed fertilizers

Treatment			Split application				Single application			
			Height			Diameter	Height			Diameter
N	P_2O_5	K_2O	1957	1958	1959	1960	1957	1958	1959	1960
- - Pounds - -			- - - - - - - - - - Inches - - - - - - - - - -							
50	25	25	25.7	68.4	115.3	4.70	25.1	66.8	111.2	4.33
100	50	50	29.8	75.4	121.1	4.77	29.0	71.7	120.9	4.63
200	100	100	26.1	67.2	102.7	4.53	26.8	69.4	113.8	4.60
400	200	200	25.5	63.3	104.1	4.47	24.6	61.2	105.9	4.43
600	300	300	29.3	75.1	118.6	4.70	30.2	70.6	115.3	4.80
Average			27.3	69.9	112.4	4.63	27.1	67.9	113.4	4.56

Table 6.--Size of trees with subsurface and surface applications of mixed fertilizers

Treatment			Subsurface application				Surface application			
			Height			Diameter	Height			Diameter
N	P_2O_5	K_2O	1957	1958	1959	1960	1957	1958	1959	1960
- - Pounds - -			- - - - - - - - - - Inches - - - - - - - - - -							
100	50	50	28.9	75.2	121.5	4.57	29.0	71.7	120.9	4.63
200	100	100	25.5	71.0	118.9	4.70	26.8	69.4	113.8	4.60
Average			27.2	73.1	120.2	4.63	27.9	70.5	117.3	4.62

Year Effect

As mentioned previously, three fertilizer treatments from the factorial experiment (N-P_2O_5-K_2O at rates of 100-50-50, 0-50-0, and 0-0-0 pounds per acre broadcast around trees) were further tested with seedlings planted in 1958. As was the case for trees planted in 1957, mixed fertilizer, or phosphate alone, stimulated additional growth on trees planted in 1958 (fig. 4). Fertilized trees 2 years after planting, on the average, were about a foot taller than trees not fertilized.

Growth was considerably less, however, for trees planted in 1958, although care was taken to treat the two plantations alike with respect to planting stock, site preparation, planting procedure, clean cultivation, and in other ways. Seedlings planted in 1957 grew in height continuously from March through September, whereas the 1958 plantings increased in height very little beyond their first flush of growth. The slower growth was attributed to subnormal precipitation, only 44 percent of the mean, during the 1958 July to September period. A normal accumulation of rainfall during the July to September period accompanied the continued rapid growth of trees planted in 1957.

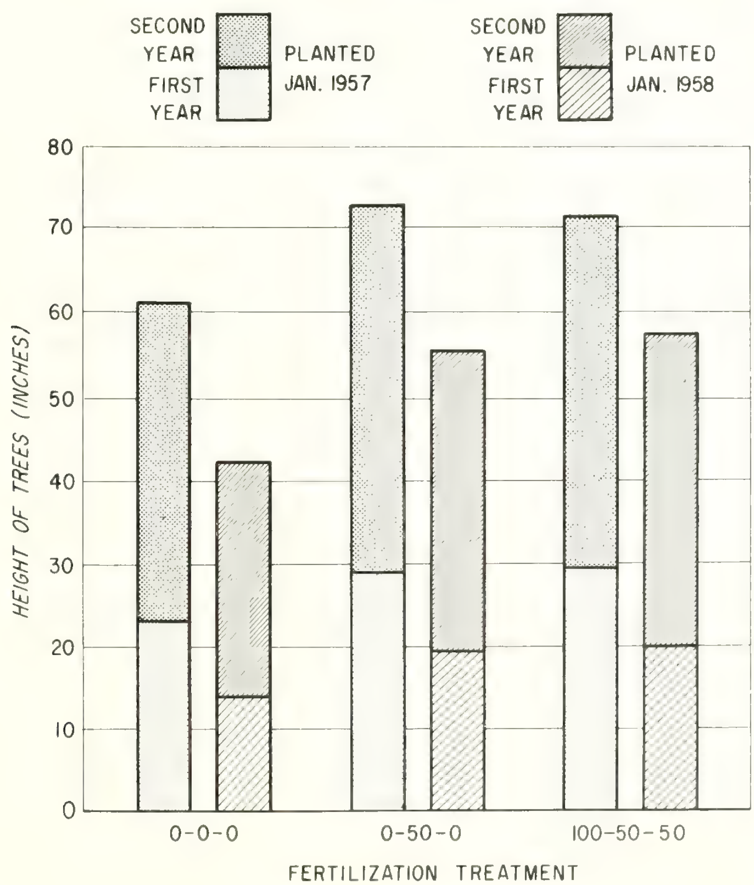

Figure 4.--Height of trees 1 and 2 years from planting related to year planted and fertilization treatment.

Year effect, as indicated by height of trees measured at the end of the first and second growing seasons for trees planted in 1957 and 1958, was greater than response to fertilizer. Fertilized trees that were planted in 1957 averaged 9.6 inches taller after 1 year and 16.1 inches taller after 2 years than trees planted in 1958 (fig. 4). On the other hand, these trees on the average were only 6.0 inches taller after 1 year and 12.9 inches taller after 2 years than trees not fertilized.

Insects and Diseases

Fertilizers broadcast around trees in 1957 and 1958, accompanied by clean cultivation, apparently increased the susceptibility of plantation trees to attack by certain insects and diseases. Attacks by tip moths, *Rhyacionia* spp., persisted through the first two growing seasons. In 1957, monthly sprays applied to individual trees, March through August, with a 1-percent DDT water emulsion killed most of the emerging larvae. The incidence of attack in other plantations not sprayed was 72 percent. In 1958, the initial spray was timed to coincide with moth emergence in the spring. By this procedure, sprays in March and in May again gave satisfactory control. Frequent DDT sprayings seemed to favor increase in spider mite populations. An acaracide (Kelthane) added to the spray mixture was followed by a sharp reduction in mites.

A severe attack by one of the phloem insects, *Dioryctria amatella* (Hulst),[3] first observed near the end of the second growing season, caused extensive damage. Because the larvae tunnel around the stem rather than vertically, they rapidly girdle a tree. Presence of larvae was readily observed by the presence of frass and pitch from open cavities in the bark. A survey in January 1959, 2 years from planting, showed girdling in 29.5 percent of the trees. A year later the incidence of attacks had increased to 35.6 percent. By June 21, 1960, losses charged to girdling and cankering were 10.5 percent and to stem cankering alone 0.8 percent. About one-third of the dead trees with *Dioryctria* attacks also had stem cankers. Only a few new attacks were observed in 1960.

Attacks by *Dioryctria* were closely related to fertilization treatment. Fertilizer mixtures in the factorial experiment of either N, P_2O_5, or K_2O at the 100-pound per acre rate resulted in a highly significant increase in the incidence of insect attack (table 7). Of the three components, incidence of attack was most closely associated with mixtures containing phosphorus. Even at the 50-pound rate, phosphate in mixed fertilizers increased insect attack fourfold over treatments containing no phosphate. Again, injury was most prevalent among fast growing trees. An increase in the incidence of attacks with increase in height of trees as tested by chi-square analysis was significant at the 1-percent level (fig. 5). As was the case with rust cankers and tip moth, damage was negligible among slow-growing trees of the same size in an adjoining plantation.

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[3] Identified by E. P. Merkel, Entomologist, Lake City Research Center.

Table 7.--Percent of trees with Dioryctria amatella in relation to mixed fertilizer component

Component	Rate 1/			Least significant difference (5 percent)
	0	1	2	
	Percent			
N	21.1	46.5	32.4	14.8
P_2O_5	9.9	40.8	49.3	14.8
K_2O	32.4	21.1	46.5	14.8

1/ A 3 x 3 x 3 factorial with N at 0, 100, and 200 pounds per acre, and P_2O_5 and K_2O at 0, 50, and 100 pounds per acre.

Southern fusiform rust (Cronartium fusiforme), of no consequence during the first year, caused widespread cankering during the second growing season. By the second winter, 10.3 percent of test trees had stem cankers. An adjoining plantation established in wiregrass sod contained very few cankers. The trees, planted in 1955 for another study, grew much slower and at 4 years from planting averaged approximately the same height in 1958 as trees in the 2-year-old fertilized plantation. These observations agree with those in Alabama where Gilmore and Livingston (1958) observed a significant increase in the number of stem cankers on cultivated and fertilized trees.

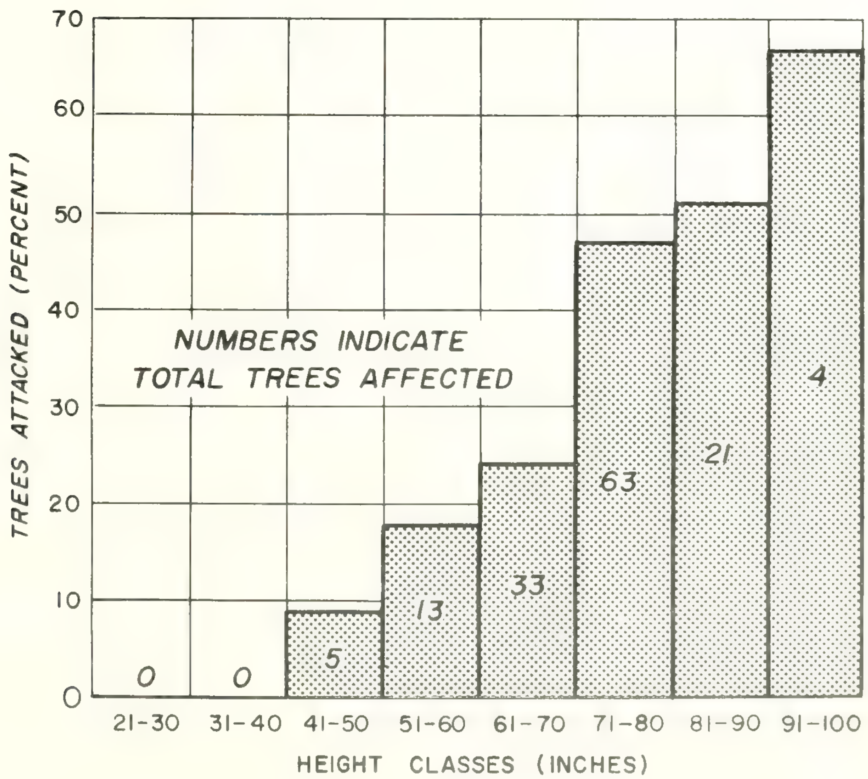

Figure 5.--Incidence of Dioryctria attacks by height classes of trees measured at end of second growing season.

DISCUSSION

Although response to fertilization was the primary aim of the experiment, it should be pointed out that cultivation alone stimulated rapid growth of slash pine seedlings. An adjoining plantation established apart from the present study in an undisturbed wiregrass "rough" provided a direct comparison. Cultivated seedlings attained a height of 60.8 inches in 2 years; in undisturbed wiregrass, seedlings required an additional 2 years to attain the same height. In other studies at Alapaha the authors observed that seedlings planted in competition with improved forage species did not benefit appreciably from broadcast application of fertilizer materials.

It is not uncommon for pine seedlings to respond to a complete fertilizer and not to a single element (Allen and Maki, 1955), or as shown in the present study, high concentrations of a fertilizer may depress growth. The depressing effect of nitrogen and potassium does not mean that the loamy sand soil type had abundant N and K, but rather that, on south Georgia soils, young slash pine do not respond to N or K in the absence of the other components of a fertilizer mixture.

Since phosphate furnished additional growth equal to applications of complete N-P-K mixtures, the phosphate alone, of course, gave cheapest additional growth. Two annual applications of superphosphate at the rate of 50 pounds of P_2O_5 per acre per year, which cost less than one-half cent per tree, gave a 20-percent increase in growth, equivalent to 1 foot in height over a 2-year period.

Responses may be expected to vary with soil type. Tests by Buckeye Cellulose Corporation in west Florida on Leon soils showed a response to N, P, and Ca, whereas on Lakeland soils N and K burned the slash pine seedlings and phosphate benefited growth (Walker, 1958). Further testing of the phosphate component on deep sands is needed to establish optimum rate, best ratio of N, P, and K, season and frequency of application, and placement of fertilizer materials.

Tests involving split application of nutrients suggest that widely varying rates of mixed N-P-K fertilizers may be used to promote growth of seedling pine trees, but that practical application would not exceed the N_1 P_1 K_1 rate (100 pounds N, 50 pounds P_2O_5, and 50 pounds K_2O). Further tests, taking into account weather effects from year to year, are needed to determine the most efficient rate and ratio in terms of cost per unit of tree growth. Differences in growth of trees planted in different years emphasize, as with farm crops, that response to fertilization is dependent in a large measure upon the prevailing weather pattern and other phenomena that occur through time.

SUMMARY

Forty-two fertilizer treatments were replicated three times in a cultivated slash pine plantation established in 1957 on Lynchburg loamy sand in southern Georgia. Seedlings were fertilized only twice, in 1957 and 1958. Average height of four trees in each replication was taken as the unit of observation.

Seedlings in check plots not fertilized reached a height of 60.8 inches in two growing seasons. In a 3 x 3 x 3 factorial experiment, where mixed fertilizers containing phosphorus were broadcast around trees at a rate of 50 pounds of P_2O_5 per acre, trees attained a height of 68.6 inches. Nitrogen and potash (K_2O), each at a 100 pounds per acre rate mixed with 0-, 50-, and 100-pound levels of phosphate, in most cases gave good response, but addition of potash without nitrogen or nitrogen without potash retarded growth. Phosphate alone at the 50-pound rate was the most efficient fertilizer tested; trees thus fertilized measured 28.7, 72.7, and 120.6 inches high 1, 2, and 3 years from planting. Nitrogen at the 200-pound rate, alone or in mixtures, retarded tree growth.

Additional tests involving (1) N-P-K with minor elements and lime, (2) split application of nutrients involving widely varying rates of N, P, and K, and (3) subsurface application of fertilizer did not reveal significant increases in growth when compared with single annual surface application of mixed fertilizers. Subsurface applications had the advantage of preventing excessive growth of weeds.

Rapid growth stimulated by cultivation and fertilization apparently increased the susceptibility of plantation trees to attacks by insects and diseases. Attacks by *Dioryctria amatella* were closely related to fertilization treatment, particularly to phosphorus. When compared with treatments containing no phosphorus, phosphate at the 50 pounds per acre rate quadrupled the incidence of *Dioryctria*. Attacks increased with an increase in growth rate of trees. Damage by this insect or by southern fusiform rust was negligible among slower growing trees planted nearby in native wiregrass sod.

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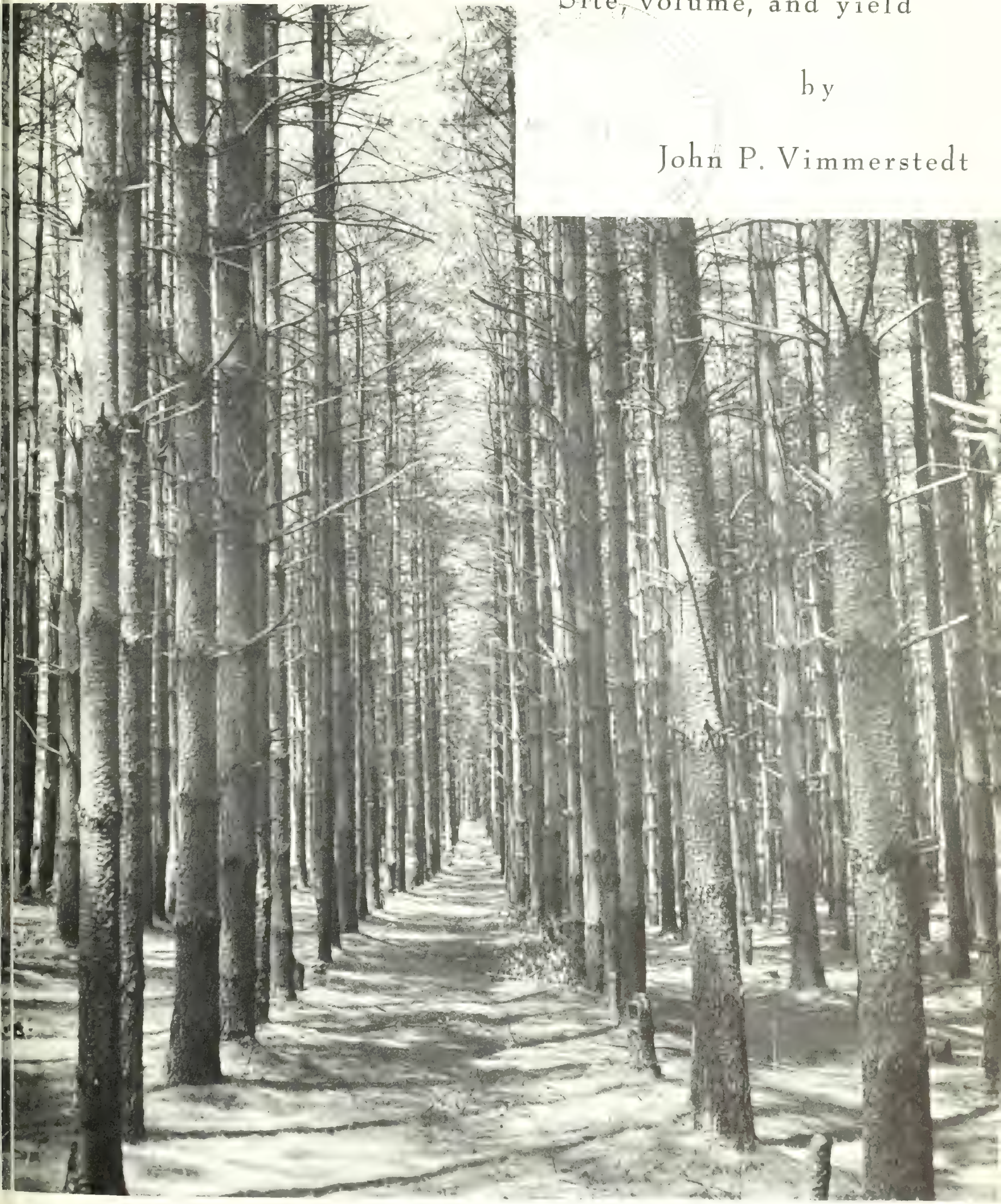
Agriculture - Asheville

Southern Appalachian White Pine Plantations

Site, volume, and yield

by

John P. Vimmerstedt



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FOREST SERVICE
SOUTHEASTERN FOREST EXPERIMENT STATION
ASHEVILLE, NORTH CAROLINA

Cover photo:

Biltmore white pine plantation established in 1908 near Asheville, North Carolina. Picture taken 1946.

Southern Appalachian White Pine Plantations

Site, volume, and yield

by

John P. Vimmerstedt [1]

INTRODUCTION

In the early 1930's several publications focused attention on the desirable characteristics of eastern white pine (Pinus strobus L.) growing in the Southern Appalachians. In 1932 Cope[2] reported on the excellent growth of natural and planted stands and their relative freedom from blister rust and white pine weevil. After an extensive survey he concluded: "In North Carolina, Tennessee, and north Georgia, where white pine has shown such excellent growth rates, the amount of ribes (R. cynosbati) present in the altitudinal zones in which white pine thrives is so small that eradication costs will be almost negligible." The following year Barrett[3] published a chart comparing the diameter growth of white pine and its associates. At all ages from 20 to 120 years the growth of white pine was more rapid than that of the other species, the nearest competitor being yellow-poplar. In the same year Kimberly[4] published results of a study of white pine growth rates in New England and the Southern Appalachians. He found that both diameter and height growth were more rapid in the South.

With these favorable reports in the literature, and with the Biltmore plantations in North Carolina as living proof that planted white pine could succeed in the region, it is not surprising that white pine became a major species for the Civilian Conservation Corps reforestation program. Today white pine remains the preferred species for planting; from 1952 through 1960 about 20 million seedlings were planted in the 15 western counties of North Carolina.

1/ The author wishes to express thanks to Professor George M. Furnival, of Yale University, for advice on statistical matters, and to the many forest landowners in North Carolina, Tennessee, and Georgia who cooperated in the study.

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3/ Barrett, L. I. Growth rate of white pine in the southern Appalachians. Jour. Forestry 31: 570-572. 1933.

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Landowners who have invested in old-field white pine plantations are asking such questions as:

"I planted these trees 10 years ago. How long before they are big enough to cut?"

"In 20 years, what will be the volume per acre in my plantation?"

This paper should help to answer these and related questions. It contains the following information:

1. Site index curves.
2. Cubic-volume and board-foot volume tables.
3. Cubic-foot yield tables.
4. A table for predicting average stand diameter.
5. Board-foot yield tables.
6. Factors for converting cubic feet to board feet.

FIELD METHODS

A total of 78 plantations were examined during 1957-1958 in North Carolina, Tennessee, and Georgia. Sampling was limited to unburned, unthinned plantations without large openings or numerous trees of other species in the main canopy. A great variety of spacings and site qualities were encountered in the plantations (figures 1, 2, and 3). It was not possible

Figure 1.--A plantation having very close spacing of 3 x 4 feet. Plantation age is 15 years, average d. b. h. 3.3 inches.

to obtain a good distribution of plots by age, however. Distribution of yield plots by age and site index is shown in table 1. In the plantations sampled, the following observations were made:

1. Total height and age measurements on 5 or 6 dominant and codominant trees for construction of site index curves.
2. Stem taper, total height, and bark thickness measurements on 241 trees for making volume tables.
3. A complete plot tally by 1-inch diameter classes for preparation of yield tables.
4. D.b.h. and total height of 2 trees in each diameter class for construction of height/d.b.h. curves.

A total of 130 plots were established. Of these, 111 were used for preparing site index curves, and 112 for preparation of yield tables.

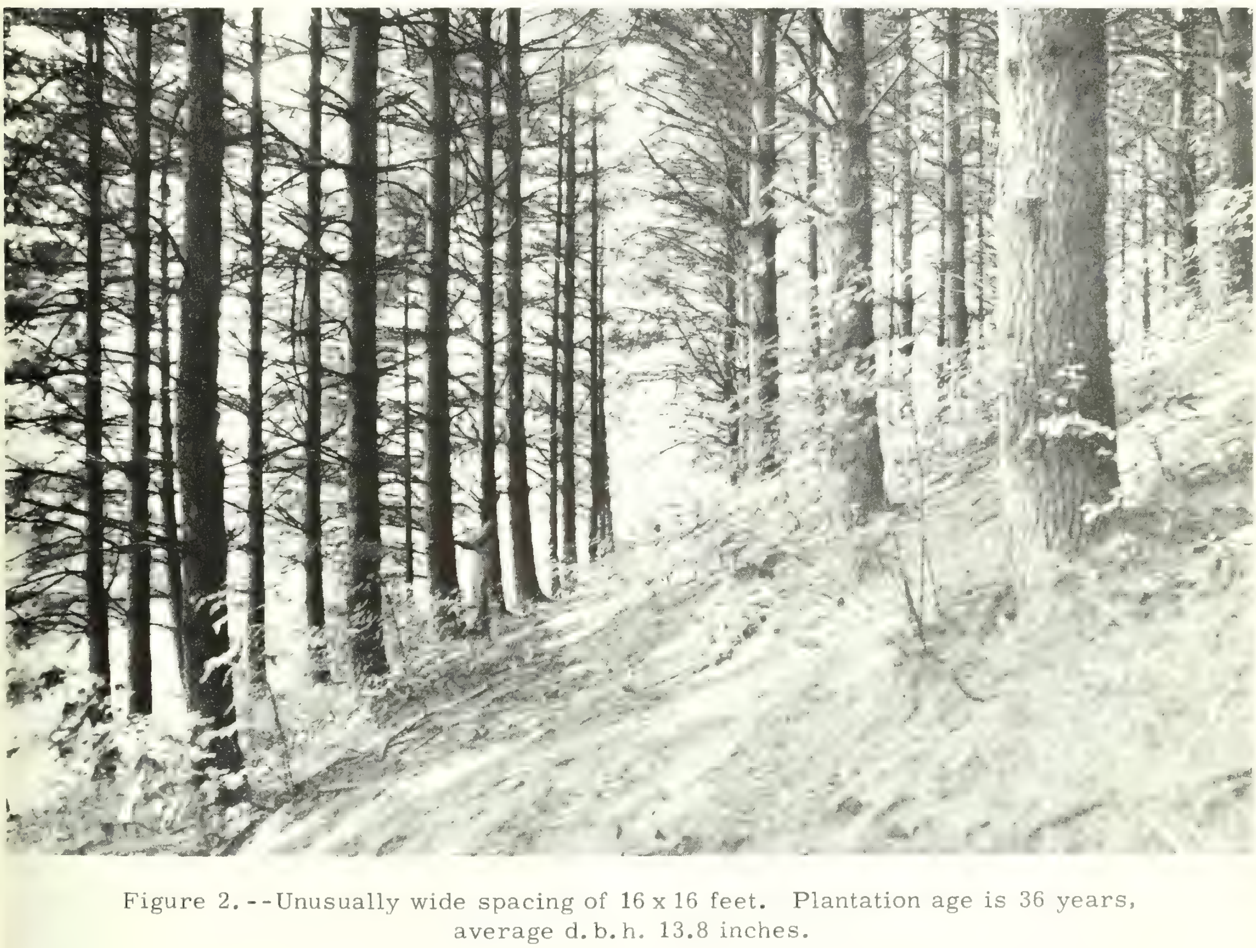

Figure 2.--Unusually wide spacing of 16 x 16 feet. Plantation age is 36 years, average d.b.h. 13.8 inches.

Table 1.--Distribution of yield plots by age and site index

Total age (years)	Site index (height in feet at 25 years)								
	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	Total
10-14	--	1	1	2	2	2	2	--	10
15-19	1	6	17	17	10	3	6	1	61
20-24	--	1	14	5	--	--	--	--	20
25-29	--	--	--	1	1	1	--	--	3
30-34	--	--	--	--	--	--	--	--	0
35-39	--	--	--	--	--	--	1	--	1
40-44	--	--	--	--	--	--	--	--	0
45-49	--	--	2	--	1	2	--	--	5
50-54	--	--	1	4	1	--	--	--	6
55-59	--	--	2	3	--	1	--	--	6
Total	1	8	37	32	15	9	9	1	112

Figure 3.--A plantation having an unusually good site index of 78 feet at 25 years of age. Plantation age is 18 years. Average height of dominant and codominant trees is 59 feet.

SITE INDEX CURVES

Site index curves were constructed from height and age data collected on 111 sample plots. The linear regression expressed in terms of site index at age 25 was:

$$\text{logarithm of site index} = \text{logarithm of total height} - 7.819225 \left(\frac{1}{25} - \frac{1}{\text{age}}\right)$$

The set of site index curves derived from this equation is shown in figure 4. The dashed line of figure 4 shows that the average plantation encountered in the study had a site index of 56. In the yield tables which follow, the quantities given for site index 55 are close to average, while site indexes above 70 are fairly rare.

The site index curves were prepared with age 25 as the index age to emphasize the fact that most of the sampled plantations were less than 30 years old. To convert to site index at age 50, multiply the site index at age 25 by 1.4335. For site indexes of 40, 50, 60, 70, and 80 at age 25 the site indexes at age 50 are 57.3, 71.7, 86.0, 100.3, and 114.7. This conversion changes the index age; it does not change the slope of the height-age relationship.

CUBIC-FOOT VOLUME TABLES

Cubic-foot volume tables were prepared from measurements on 241 trees. Volume was determined graphically and weighted regression equations of the form $\frac{\text{volume}}{(\text{DBH})^2 \text{ (total height)}} = b_o + \frac{b_1}{(\text{DBH})^2 \text{ (total height)}}$ were fitted to the data by least squares. The resulting equations for volume inside and outside bark to various top diameter limits are listed below:

1. cu.-ft. volume outside bark to 4.0-inch top o.b. = $-0.581077 + 0.0026136 (\text{DBH})^2 (\text{total height})$
2. cu.-ft. volume outside bark to 3.0-inch top o.b. = $-0.184542 + 0.00258896 (\text{DBH})^2 (\text{total height})$
3. cu.-ft. volume inside bark to 4.0-inch top o.b. = $-0.535206 + 0.00228831 (\text{DBH})^2 (\text{total height})$
4. cu.-ft. volume inside bark to 3.0-inch top o.b. = $-0.254526 + 0.00228620 (\text{DBH})^2 (\text{total height})$

Tables 2 and 3, computed from the above equations, may be used to estimate cubic-foot volume of white pine planted in old fields in the Southern Appalachian region.

Table 2.--Cubic-foot volumes (outside bark) for white pine plantations

TOP DIAMETER 4.0 INCHES OUTSIDE BARK

D. b. h. (Inches)	Total tree height (feet)															
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
	Cubic-feet															
5	.73	1.05	1.38	1.71	2.03	2.36	2.69	3.01	3.34	--	--	--	--	--	--	--
6	1.30	1.77	2.24	2.71	3.18	3.65	4.12	4.59	5.07	5.54	6.01	--	--	--	--	--
7	1.98	2.62	3.26	3.90	4.54	5.18	5.82	6.46	7.10	7.74	8.38	9.02	9.66	--	--	--
8	--	--	4.44	5.27	6.11	6.95	7.78	8.62	9.46	10.29	11.13	11.96	12.80	--	--	--
9	--	--	--	6.83	7.89	8.95	10.00	11.06	12.12	13.18	14.24	15.30	16.35	17.41	--	--
10	--	--	--	--	9.87	11.18	12.49	13.79	15.10	16.41	17.71	19.02	20.33	21.63	22.94	24.25
11	--	--	--	--	--	13.65	15.23	16.81	18.39	19.97	21.56	23.14	24.72	26.30	27.88	29.46
12	--	--	--	--	--	--	--	--	22.00	23.88	25.76	27.65	29.53	31.41	33.29	35.17
13	--	--	--	--	--	--	--	--	--	--	30.34	32.55	34.75	36.96	39.17	41.38
14	--	--	--	--	--	--	--	--	--	--	--	--	40.40	42.96	45.52	48.08
	TOP DIAMETER 3.0 INCHES OUTSIDE BARK															
4	.64	.85	1.06	1.27	1.48	1.68	1.89	2.10	--	--	--	--	--	--	--	--
5	1.11	1.44	1.76	2.09	2.41	2.73	3.06	3.38	3.70	--	--	--	--	--	--	--
6	1.68	2.15	2.61	3.08	3.54	4.01	4.48	4.94	5.41	5.87	6.34	--	--	--	--	--
7	2.36	2.99	3.62	4.26	4.89	5.52	6.16	6.79	7.43	8.06	8.70	9.33	9.96	--	--	--
8	--	--	4.79	5.61	6.44	7.27	8.10	8.93	9.76	10.59	11.41	12.24	13.07	--	--	--
9	--	--	--	7.15	8.20	9.25	10.30	11.35	12.40	13.45	14.49	15.54	16.59	17.64	--	--
10	--	--	--	--	10.17	11.47	12.76	14.05	15.35	16.64	17.94	19.23	20.53	21.82	23.12	24.41
11	--	--	--	--	--	13.91	15.48	17.04	18.61	20.18	21.74	23.31	24.88	26.44	28.01	29.58
12	--	--	--	--	--	--	--	20.31	22.18	24.05	25.91	27.78	29.64	31.50	33.37	35.23
13	--	--	--	--	--	--	--	--	--	--	30.44	32.63	34.82	37.01	39.19	41.38
14	--	--	--	--	--	--	--	--	--	--	--	--	40.41	42.96	45.52	48.08

Table 3.--Cubic-foot volumes (inside bark) for white pine plantations

TOP DIAMETER 4.0 INCHES OUTSIDE BARK

D. b. h. (Inches)	Total tree height (feet)															
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
	Cubic-feet															
5	.60	.89	1.18	1.47	1.75	2.04	2.33	2.61	2.90	--	--	--	--	--	--	--
6	1.11	1.52	1.94	2.35	2.76	3.17	3.58	4.00	4.41	4.82	5.23	--	--	--	--	--
7	1.70	2.27	2.83	3.39	3.95	4.51	5.07	5.63	6.19	6.75	7.31	7.87	8.43	--	--	--
8	--	--	3.86	4.59	5.32	6.06	6.79	7.52	8.25	8.98	9.72	10.45	11.18	--	--	--
9	--	--	--	5.95	6.88	7.81	8.73	9.66	10.59	11.51	12.44	13.37	14.29	15.22	--	--
10	--	--	--	--	8.62	9.76	10.91	12.05	13.19	14.34	15.48	16.63	17.77	18.92	20.06	21.20
11	--	--	--	--	--	11.92	13.31	14.69	16.08	17.46	18.85	20.23	21.62	23.00	24.38	25.77
12	--	--	--	--	--	--	--	--	19.24	20.88	22.53	24.18	25.83	27.47	29.12	30.77
13	--	--	--	--	--	--	--	--	--	--	26.54	28.47	30.40	32.34	34.27	36.20
14	--	--	--	--	--	--	--	--	--	--	--	--	35.35	37.59	39.83	42.07
	TOP DIAMETER 3.0 INCHES OUTSIDE BARK															
4	.48	.66	.84	1.03	1.21	1.39	1.57	1.75	--	--	--	--	--	--	--	--
5	.89	1.17	1.46	1.75	2.03	2.32	2.60	2.89	3.17	--	--	--	--	--	--	--
6	1.39	1.80	2.21	2.63	3.04	3.45	3.86	4.27	4.68	5.10	5.51	--	--	--	--	--
7	1.99	2.55	3.11	3.67	4.23	4.79	5.35	5.91	6.47	7.03	7.59	8.15	8.71	--	--	--
8	--	--	4.13	4.87	5.60	6.33	7.06	7.79	8.52	9.26	9.99	10.72	11.45	--	--	--
9	--	--	--	6.23	7.15	8.08	9.00	9.93	10.86	11.78	12.71	13.63	14.56	15.49	--	--
10	--	--	--	--	8.89	10.03	11.18	12.32	13.46	14.61	15.75	16.89	18.04	19.18	20.32	21.46
11	--	--	--	--	--	12.19	13.58	14.96	16.34	17.73	19.11	20.49	21.88	23.26	24.64	26.03
12	--	--	--	--	--	--	--	--	19.50	21.14	22.79	24.44	26.08	27.73	29.37	31.02
13	--	--	--	--	--	--	--	--	--	--	26.79	28.72	30.65	32.59	34.52	36.45
14	--	--	--	--	--	--	--	--	--	--	--	--	35.59	37.83	40.07	42.31

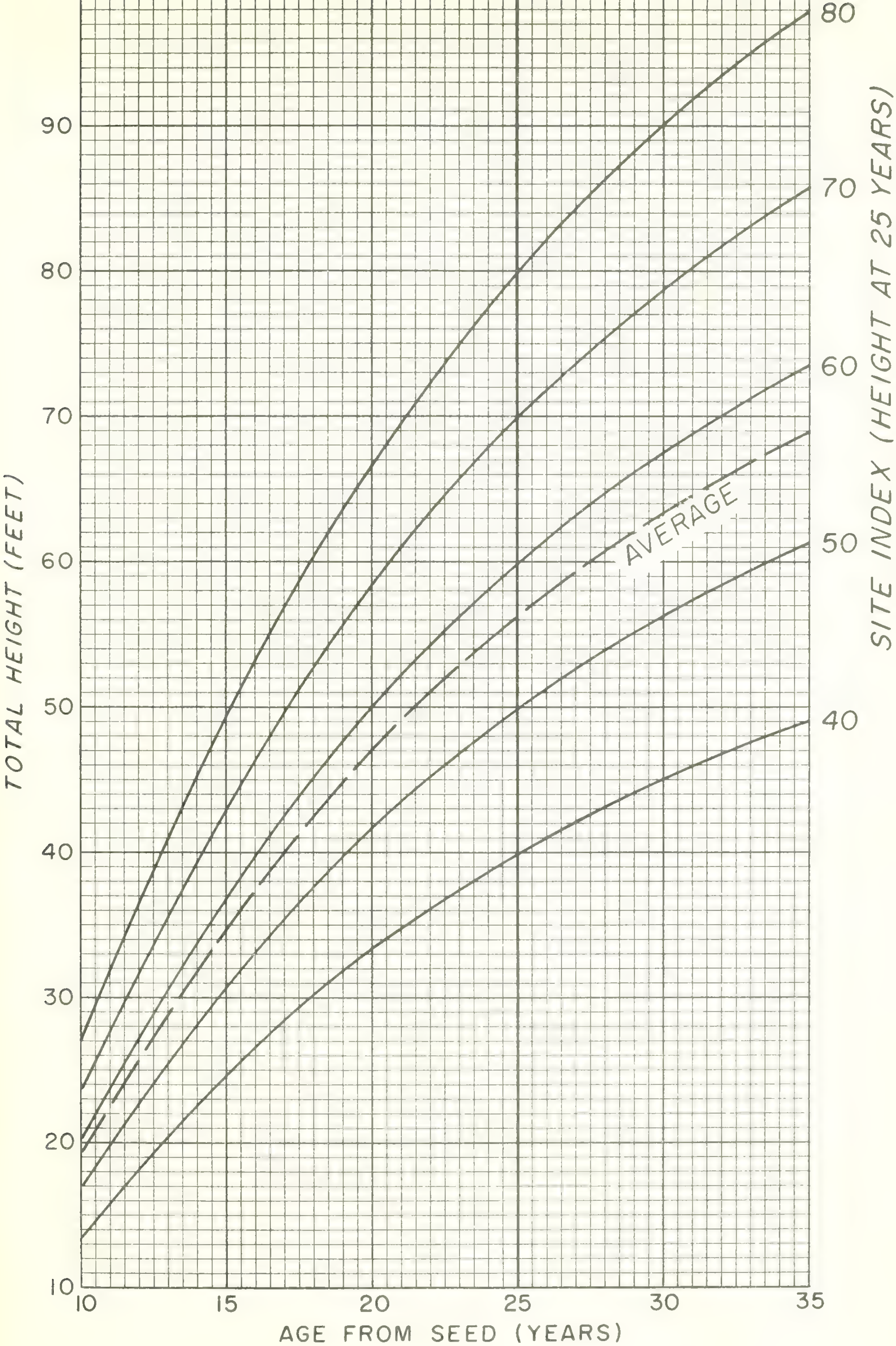

Figure 4.--Site index curves for old-field white pine plantations in the Southern Appalachians. Index age is 25 years.

BOARD-FOOT VOLUME TABLE

A board-foot volume table for small saw logs was prepared from 100 trees which contained at least one 8-foot log with a 6-inch diameter inside bark at the small end. The regression equation for the relationship between volume, D^2H, and total height is:

$$\text{bd.-ft. volume to 6.0-inch top i.b.} = 0.0142908(D^2H) - 0.299194H - 7.797400.$$

Table 4 gives board-foot volumes (International $\frac{1}{4}$-inch rule) for trees of various heights and diameters.

Table 4.--Board-foot volume (International $\frac{1}{4}$-inch rule) for white pine, by diameter and total tree height
TOP DIAMETER 6.0 INCHES INSIDE BARK

D. b. h. (inches)	Total height (feet)										
	35	40	45	50	55	60	65	70	75	80	85
	Board feet										
7	6	8	10	12	14	16	18	20	22	24	--
8	14	17	20	23	26	29	32	35	38	41	--
9	22	26	31	35	39	44	48	52	57	61	65
10	--	37	43	49	54	60	66	71	77	83	88
11	--	--	57	64	71	78	85	92	99	107	114
12	--	--	--	80	89	98	106	115	124	133	142

In order to give some idea of the reliability of table 4, the confidence intervals shown in table 5 were calculated. This table is interpreted as follows:

1. For any one tree with 10-inch d.b.h. and height of 50 feet, the chances are 95 out of 100 that the actual board-foot volume will be in the interval 35 to 63, the most probable value being 49 board feet.
2. For the whole population of trees of 10-inch d.b.h. and height 50 feet, the chances are 95 out of 100 that the actual average board-foot volume of the group is in the interval 47.3 to 50.7, the most probable value again being 49 board feet.

Table 5.--Confidence intervals for selected board-foot volumes at 95-percent level

Tree d. b. h. (inches)	Total height (feet)									
	40		50		60		70		80	
	Individual tree	Population	Individual tree	Population	Individual tree	Population	Individual tree	Population	Individual tree	Population
8	±14.09	±2.04	±14.01	±1.55	±14.05	±1.74	±14.15	±2.52	±14.35	±3.47
10	±14.13	±2.40	±14.05	±1.74	±14.01	±1.53	±14.05	±1.84	±14.17	±2.62
12	±14.29	±3.23	±14.21	±2.85	±14.19	±2.74	±14.23	±2.93	±14.33	±3.37

CUBIC-FOOT YIELDS

By means of the data from 112 sample plots, the relation between plantation cubic-foot volume and age, site index, and spacing was investigated via regression techniques. The following predicting equation was superior to all others tested, accounting for 90 percent of the total variation:

$$\begin{aligned}&\text{logarithm of cubic-foot volume per acre, outside bark}\\ &\text{to 3.0-inch top o.b.} = 0.90555 - 24.8002\left(\frac{1}{\text{age}}\right)\\ &\quad + 1.40983\,[\text{logarithm (site index)}]\\ &\quad + 0.000789563\left(\frac{\text{original No. trees per acre}}{\text{age}}\right)\\ &\quad + 0.908740\left[\text{logarithm}\left(\frac{\text{site index} \times 10}{\text{age}}\right)\right]\end{aligned}$$

Cubic-foot yields predicted from this equation for plantations of various ages, site indexes, and original spacings are shown in table 6. In sampling for this study, it was not possible to find many plantations between the ages of 25 and 45 years, or with wide original spacing. Thus, although yields are given for spacings up to 12 x 12 feet and for ages up to 35 years, the volumes predicted for closer spacings and younger ages are more reliable.

Table 6.--Cubic-foot yield of white pine per acre, including bark, by site, age, and original spacing; all trees 3.0-inch d. b. h. and larger to a 3.0-inch top (o. b.) diameter

Age (years)	Average height dominants and codominants	Original spacing (feet)								
		4 x 4	5 x 5	6 x 6	6 x 7	7 x 7	8 x 8	9 x 9	10 x 10	12 x 12
	Feet	Cubic feet								
		SITE INDEX 45								
10	15	298	249	226	219	213	205	200	196	192
15	28	1,171	1,040	975	955	938	914	898	888	873
20	38	2,150	1,967	1,874	1,845	1,820	1,786	1,763	1,747	1,725
25	45	2,958	2,754	2,650	2,617	2,589	2,550	2,524	2,504	2,481
30	51	3,548	3,344	3,237	3,205	3,175	3,135	3,108	3,089	3,065
35	55	3,955	3,758	3,656	3,623	3,596	3,557	3,531	3,512	3,487
		SITE INDEX 50								
10	17	380	318	289	280	272	262	255	251	245
15	31	1,495	1,327	1,245	1,219	1,197	1,167	1,147	1,133	1,115
20	42	2,746	2,512	2,393	2,357	2,324	2,280	2,251	2,230	2,204
25	50	3,777	3,516	3,383	3,341	3,305	3,255	3,223	3,197	3,167
30	56	4,531	4,271	4,134	4,093	4,055	4,004	3,969	3,945	3,914
35	61	5,050	4,800	4,669	4,627	4,592	4,543	4,509	4,485	4,454
		SITE INDEX 55								
10	19	474	397	360	349	340	327	319	313	305
15	34	1,865	1,656	1,553	1,521	1,493	1,456	1,431	1,414	1,391
20	46	3,425	3,133	2,985	2,940	2,899	2,844	2,808	2,782	2,749
25	55	4,711	4,386	4,220	4,168	4,123	4,061	4,019	3,988	3,951
30	62	5,652	5,327	5,157	5,105	5,058	4,995	4,951	4,920	4,882
35	68	6,298	5,986	5,822	5,770	5,727	5,665	5,623	5,594	5,554

Table 6.--Cubic-foot yield of white pine per acre, including bark, by site, age, and original spacing; all trees 3.0-inch d.b.h. and larger to a 3.0-inch top (o.b.) diameter (continued)

Age (years)	Average height dominants and codominants	Original spacing (feet)								
		4 x 4	5 x 5	6 x 6	6 x 7	7 x 7	8 x 8	9 x 9	10 x 10	12 x 12
	Feet	Cubic feet								
		SITE INDEX 60								
10	20	580	485	440	427	416	400	390	383	373
15	37	2,282	2,026	1,900	1,861	1,827	1,782	1,751	1,729	1,702
20	50	4,191	3,834	3,653	3,597	3,547	3,480	3,436	3,404	3,363
25	60	5,765	5,368	5,164	5,100	5,045	4,970	4,918	4,881	4,835
30	68	6,915	6,518	6,310	6,246	6,189	6,111	6,058	6,020	5,973
35	74	7,706	7,323	7,124	7,060	7,007	6,931	6,880	6,844	6,795
		SITE INDEX 65								
10	22	699	584	530	514	500	482	469	461	449
15	40	2,747	2,439	2,287	2,240	2,199	2,144	2,108	2,082	2,048
20	54	5,045	4,615	4,397	4,330	4,271	4,190	4,136	4,098	4,049
25	65	6,939	6,461	6,216	6,139	6,073	5,981	5,920	5,875	5,820
30	73	8,323	7,845	7,594	7,518	7,449	7,355	7,291	7,246	7,190
35	80	9,277	8,817	8,576	8,500	8,435	8,344	8,283	8,240	8,181
		SITE INDEX 70								
10	24	830	693	630	610	594	572	557	547	534
15	43	3,261	2,896	2,715	2,660	2,612	2,546	2,503	2,472	2,432
20	58	5,991	5,480	5,222	5,142	5,071	4,975	4,911	4,866	4,807
25	70	8,241	7,674	7,382	7,291	7,213	7,104	7,031	6,978	6,912
30	79	9,883	9,315	9,018	8,927	8,845	8,734	8,658	8,604	8,537
35	86	11,015	10,469	10,181	10,093	10,016	9,908	9,836	9,784	9,714
		SITE INDEX 75								
10	26	974	814	739	716	697	671	654	642	626
15	46	3,828	3,399	3,187	3,122	3,066	2,989	2,938	2,902	2,855
20	63	7,031	6,431	6,128	6,034	5,951	5,838	5,764	5,711	5,642
25	75	9,669	9,003	8,662	8,555	8,463	8,335	8,249	8,187	8,110
30	84	11,601	10,935	10,585	10,479	10,382	10,252	10,163	10,100	10,021
35	92	12,930	12,291	11,954	11,847	11,757	11,631	11,545	11,484	11,403

AVERAGE STAND DIAMETER

The same 112 sample plots used in making the cubic-foot yield tables were also used to determine the relationship between average basal area per tree and age, site index, and spacing. The regression equation for this relationship, accounting for 93 percent of the total variation, is:

$$\text{logarithm average basal area per tree} + 2 = 1.42826$$
$$- 0.463267 \left[\text{logarithm} \left(\frac{\text{original No. trees per acre}}{\text{age}}\right)\right]$$
$$+ 0.00717020 \text{ (site index)} + 0.0106594 \text{ (age)}.$$

The diameter of the tree of average basal area in terms of age, site index, and original spacing is shown in table 7.

Table 7.--Diameter at breast height of tree of average basal area

SITE INDEX 45

Age (years)	Original spacing (feet)								
	4 x 4	5 x 5	6 x 6	6 x 7	7 x 7	8 x 8	9 x 9	10 x 10	12 x 12
	Inches								
10	3.1	3.5	3.8	3.9	4.1	4.3	4.6	4.8	5.2
15	3.7	4.1	4.4	4.6	4.7	5.1	5.3	5.6	6.1
20	4.2	4.6	5.0	5.2	5.4	5.7	6.1	6.4	6.9
25	4.7	5.2	5.6	5.8	6.0	6.4	6.8	7.1	7.8
30	5.2	5.7	6.2	6.5	6.7	7.1	7.5	7.9	8.6
35	5.7	6.3	6.7	7.1	7.4	7.8	8.3	8.7	9.5
SITE INDEX 50									
10	3.3	3.6	3.9	4.1	4.2	4.5	4.8	5.0	5.4
15	3.8	4.2	4.6	4.8	4.9	5.3	5.5	5.8	6.4
20	4.3	4.8	5.2	5.4	5.6	6.0	6.3	6.6	7.2
25	4.9	5.4	5.9	6.1	6.3	6.7	7.1	7.4	8.1
30	5.4	6.0	6.5	6.7	7.0	7.4	7.8	8.2	9.0
35	5.9	6.6	7.2	7.4	7.7	8.2	8.6	9.1	9.9
SITE INDEX 55									
10	3.4	3.8	4.1	4.3	4.4	4.7	5.0	5.2	5.7
15	4.0	4.4	4.8	5.0	5.2	5.5	5.8	6.1	6.6
20	4.5	5.0	5.5	5.6	5.9	6.2	6.6	6.9	7.5
25	5.1	5.6	6.1	6.3	6.6	7.0	7.4	7.7	8.4
30	5.6	6.2	6.8	7.0	7.3	7.7	8.2	8.6	9.3
35	6.2	6.9	7.5	7.7	8.0	8.5	9.0	9.5	10.3
SITE INDEX 60									
10	3.5	3.9	4.3	4.4	4.6	4.9	5.2	5.4	5.9
15	4.1	4.6	5.0	5.2	5.4	5.7	6.0	6.3	6.9
20	4.7	5.2	5.7	5.9	6.1	6.5	6.9	7.2	7.8
25	5.3	5.9	6.4	6.6	6.8	7.3	7.7	8.1	8.8
30	5.9	6.5	7.1	7.3	7.6	8.1	8.5	8.9	9.7
35	6.4	7.1	7.8	8.1	8.4	8.9	9.4	9.8	10.7
SITE INDEX 65									
10	3.7	4.1	4.5	4.6	4.8	5.1	5.4	5.7	6.2
15	4.3	4.8	5.2	5.4	5.6	6.0	6.3	6.6	7.2
20	4.9	5.4	5.9	6.1	6.4	6.8	7.1	7.5	8.2
25	5.5	6.1	6.6	6.9	7.1	7.6	8.0	8.4	9.1
30	6.1	6.7	7.4	7.6	7.9	8.4	8.9	9.3	10.1
35	6.7	7.5	8.1	8.4	8.7	9.3	9.8	10.3	11.2
SITE INDEX 70									
10	3.9	4.3	4.7	4.8	5.0	5.3	5.6	5.9	6.4
15	4.5	5.0	5.4	5.6	5.8	6.2	6.6	6.9	7.5
20	5.1	5.7	6.2	6.4	6.6	7.1	7.5	7.8	8.5
25	5.7	6.4	6.9	7.1	7.4	7.9	8.3	8.8	9.5
30	6.4	7.0	7.7	7.9	8.2	8.8	9.3	9.7	10.6
35	7.0	7.8	8.4	8.8	9.1	9.6	10.2	10.7	11.7
SITE INDEX 75									
10	4.0	4.5	4.8	5.0	5.2	5.5	5.8	6.1	6.7
15	4.7	5.2	5.7	5.9	6.1	6.4	6.8	7.2	7.8
20	5.3	5.9	6.4	6.7	6.9	7.4	7.8	8.2	8.9
25	6.0	6.6	7.2	7.5	7.7	8.2	8.7	9.1	9.9
30	6.6	7.3	8.0	8.3	8.6	9.1	9.6	10.1	11.0
35	7.3	8.1	8.8	9.1	9.5	10.1	10.6	11.1	12.2

BOARD-FOOT YIELDS

Since white pine is more valuable as lumber than as pulpwood, board-foot yields of plantations are of considerable interest. In order to construct board-foot yield tables, the relation between the board-foot/cubic-foot ratio of 90 sample plots and plantation height and diameter was determined. No plot of a particular diameter class was used unless all the plots in that diameter class had some board-foot volume. Plantations with an average diameter less than 4.6 inches were not used.

The regression equation for predicting board-foot/cubic-foot ratio is:

$$\frac{\text{board feet (International } \tfrac{1}{4}\text{-inch rule to 6.0-inch top i.b.)}}{\text{cubic feet (outside bark to 3.0-inch top o.b.)}}$$

$$= 9.607418 - 3.538879 \left[\text{logarithm} \left(\frac{100}{\text{average plantation basal area}}\right)\right]$$

$$+ 0.0282083 \text{ (height of dominant stand).}$$

This board-foot/cubic-foot ratio is for stands, not for individual trees. The equation accounted for 95 percent of the total variation encountered. Table 8 was constructed by multiplying the cubic-foot yields of table 6 by the board-foot/cubic-foot ratio obtained from the above equation. It is interesting to note that while cubic-foot yield decreases with increasing space per tree, board-foot yield increases. This is due to the larger average diameter of plantations with wider spacings.

Table 8.--Board-foot yield of white pine per acre to 6.0-inch top diameter i.b., International $\frac{1}{4}$-inch rule

Age (years)	Original spacing (feet)								
	4 x 4	5 x 5	6 x 6	6 x 7	7 x 7	8 x 8	9 x 9	10 x 10	12 x 12
	Board feet								
SITE INDEX 45									
10	--	--	--	--	--	--	--	--	6
15	--	--	--	--	86	257	403	531	753
20	--	557	1,016	1,199	1,388	1,702	1,974	2,217	2,640
25	1,542	2,311	2,912	3,157	3,411	3,848	4,231	4,575	5,175
30	3,581	4,435	5,137	5,427	5,736	6,256	6,728	7,150	7,883
35	5,650	6,561	7,332	7,659	8,003	8,586	9,117	9,588	10,449
SITE INDEX 50									
10	--	--	--	--	--	--	--	--	50
15	--	--	107	238	366	579	761	921	1,200
20	577	1,327	1,884	2,110	2,342	2,731	3,071	3,377	3,914
25	2,980	3,892	4,623	4,925	5,239	5,783	6,266	6,697	7,454
30	5,837	6,857	7,714	8,073	8,457	9,107	9,699	10,233	11,159
35	8,723	9,815	10,758	11,164	11,592	12,323	12,989	13,585	14,678
SITE INDEX 55									
10	--	--	--	--	--	--	--	37	116
15	--	69	467	623	777	1,034	1,256	1,452	1,795
20	1,551	2,416	3,075	3,346	3,625	4,097	4,513	4,888	5,549
25	4,980	6,030	6,898	7,261	7,642	8,304	8,891	9,424	10,358
30	8,893	10,071	11,092	11,524	11,991	12,786	13,510	14,164	15,310
35	12,780	14,048	15,173	15,664	16,186	17,078	17,896	18,633	19,980

Table 8. --Board-foot yield of white pine per acre to 6.0-inch top diameter i.b., International ¼-inch rule (continued)

SITE INDEX 60

Age (years)	Original spacing (feet)								
	4 x 4	5 x 5	6 x 6	6 x 7	7 x 7	8 x 8	9 x 9	10 x 10	12 x 12
	Board feet								
10	--	--	--	--	--	--	56	112	207
15	--	518	978	1,161	1,342	1,647	1,912	2,146	2,561
20	2,925	3,896	4,658	4,975	5,305	5,866	6,365	6,815	7,612
25	7,637	8,817	9,824	10,250	10,701	11,493	12,196	12,840	13,970
30	12,849	14,177	15,369	15,878	16,434	17,382	18,256	19,045	20,432
35	17,940	19,374	20,695	21,276	21,898	22,965	23,953	24,842	26,475
SITE INDEX 65									
10	--	--	--	--	--	73	150	216	328
15	418	1,148	1,668	1,877	2,087	2,442	2,754	3,031	3,521
20	4,760	5,823	6,687	7,052	7,437	8,092	8,677	9,211	10,159
25	11,052	12,344	13,491	13,985	14,509	15,435	16,268	17,030	18,376
30	17,860	19,322	20,682	21,276	21,924	23,037	24,071	25,010	26,666
35	24,399	25,987	27,502	28,182	28,906	30,165	31,337	32,396	34,345
SITE INDEX 70									
10	--	--	--	15	81	186	275	352	483
15	1,195	1,982	2,562	2,799	3,038	3,445	3,806	4,128	4,702
20	7,122	8,258	9,222	9,636	10,073	10,828	11,507	12,130	13,240
25	15,333	16,717	17,999	18,561	19,164	20,234	21,203	22,096	23,675
30	24,021	25,594	27,126	27,804	28,550	29,842	31,047	32,145	34,091
35	32,261	33,984	35,691	36,479	37,317	38,780	40,152	41,390	43,683
SITE INDEX 75									
10	--	--	68	143	217	336	437	525	676
15	2,224	3,056	3,691	3,955	4,223	4,686	5,097	5,468	6,133
20	10,064	11,251	12,309	12,771	13,265	14,123	14,905	15,622	16,909
25	20,582	22,026	23,441	24,072	24,753	25,975	27,088	28,118	29,952
30	31,503	33,161	34,857	35,624	36,471	37,951	39,341	40,612	42,873
35	41,736	43,577	45,483	46,362	47,321	49,003	50,581	52,017	54,689

USE OF TABLES

The tables are easy to use. As an example, consider a plantation established 8 years ago with 2-year-old seedlings planted at a spacing of 8 x 8 feet. Average total height of 6 dominant and codominant trees is presently 20 feet. Figure 4 shows that this plantation has a site index of 60. Knowledge of tree age, initial spacing, and site index permits a determination to be made of present yields, plus a forecast of the future behavior of the plantation, by entering appropriate tables. Predictions for the plantation at age 20 are as follows:

1. From table 6: volume per acre = 3,480 cubic feet.
2. From table 7: diameter of tree of average basal area = 6.5 inches.
3. From table 8: board-foot volume per acre = 5,866 board feet.

Spacing-Environmental Relationships in a Slash Pine Plantation

by

William R. Harms

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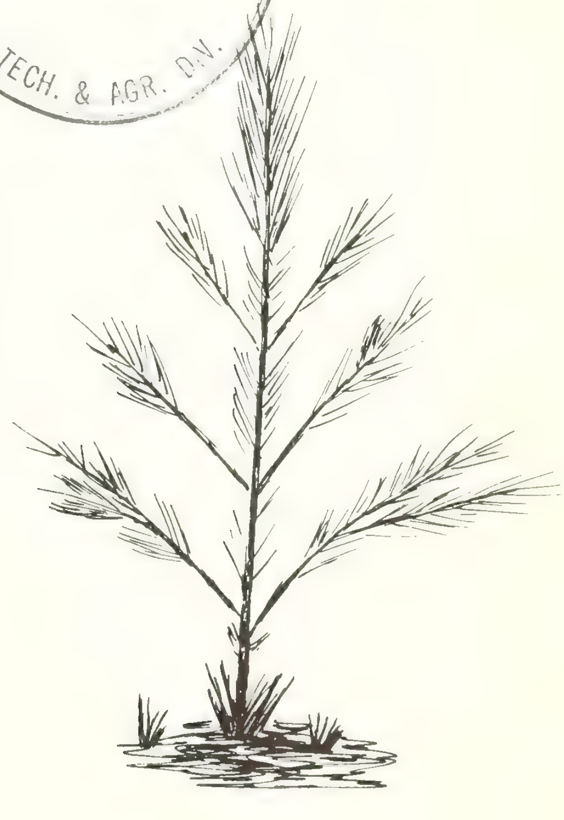

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
SOUTHEASTERN FOREST EXPERIMENT STATION
ASHEVILLE, NORTH CAROLINA

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Spacing-Environmental Relationships in a Slash Pine Plantation

by

William R. Harms

INTRODUCTION

The influence of tree spacing on the relationship between diameter growth and prevailing environmental conditions was investigated in a 6-year-old slash pine (Pinus elliottii Engelm. var. elliottii) plantation on the George Walton Experimental Forest, Dooly County, Georgia. The study was designed to determine whether differences in diameter growth between three spacings were related to soil moisture, rainfall, evaporation, wind, and soil and air temperature.

In many areas of the South soil moisture frequently becomes limiting to growth at sometime during the growing season, whereas light, temperature, and other environmental factors generally are adequate. Because of this, considerable emphasis was placed on the growth-soil moisture aspect of the study in an attempt to provide a basis for evaluating the importance of moisture to young plantation growth in the middle coastal plain area of Georgia.

Tree growth-soil moisture relationships have received considerable attention in recent years. Many studies have been made in both natural stands (2, 3, 5), and plantations (4, 8, 9, 14). Zahner and Whitmore (14) reported that widely spaced trees in a radically thinned loblolly pine (Pinus taeda L.) plantation in Arkansas made diameter growth into late fall while unthinned control plots ceased growth by midsummer. They were able to relate growth to crown and root development following thinning, and to available soil moisture. On the control plots the soil dried very rapidly, nearing the wilting point by midsummer, while moisture on the thinned plots remained high until late summer or early fall. Della-Bianca and Dils (4) found that radial growth of planted red pine (Pinus resinosa Ait.) continued longer in thinned than in unthinned stands. They attributed this in part to more favorable soil moisture conditions in the thinned stands resulting from reduced interception and less root competition. McClurkin (9) reported similar results from a thinning study in shortleaf pine (Pinus echinata Mill.) plantations in Mississippi.

No work of this kind has been published for the south Atlantic coastal plain, or for slash pine. Since slash pine is the most widely planted of the southern pines, this study was undertaken to gain a better understanding of the interrelationships between plantation spacing, environmental conditions, and the diameter growth of this species in the middle coastal plain of Georgia.

METHODS

The investigation was made during the growing seasons of 1957 and 1958 in a slash pine plantation spacing study established on the experimental forest in 1952 (1). The parent study was planted in 3/4-acre plots of a randomized block design in a field that had been under cultivation the previous year. Two blocks (A and B) were established, with each block consisting of one plot for each of eight different spacings. Both replications of the 6 x 6-foot (1,210 trees per acre), 8 x 8-foot (681 trees per acre), and 15 x 15-foot (194 trees per acre) spacings were chosen for study.

Soils on the study area belong to the Gilead and Lakeland series. These are somewhat well to excessively drained loamy sands derived from irregularly bedded sands, clays, and gravels of the middle coastal plain. Thickness of the surface layer varied from 10 to 30 inches.

A rectangular plot 0.2 acre in size was established in each spacing for diameter growth and soil moisture measurements.

Aluminum growth bands (7) were attached at d.b.h. to ten trees in each of the six plots. Growth to the 0.01 inch was recorded weekly from March through October of both years.

Soil moisture was determined gravimetrically from tube samples (10) collected at four randomly selected spots in each plot. Samples were taken at 2- to 3-day intervals from the 0- to 6-, 6- to 12-, and 12- to 18-inch layers, and at biweekly intervals from the 30- to 36- and 48- to 54-inch layers.

Three 3-inch core samples were taken from each plot and sampling depth for bulk density and 0.06 and 0.3 atmosphere tension determinations. Composite bulk samples were also collected and analyzed in the laboratory for texture and 15-atmosphere moisture content.

A weather station was installed near the study area to provide daily records of air temperature and relative humidity, soil temperature at depths of $\frac{1}{2}$, 6, and 24 inches, rainfall, and open pan evaporation. A totalizing anemometer was installed at crown height in the center of the study area. Complete records of soil temperature, evaporation, and wind were not obtained for 1957; consequently, these factors were included only in the 1958 analysis.

The relationships between diameter growth, soil moisture, and the various weather factors were analyzed by multiple regression techniques. Each spacing was first analyzed by year. Differences between spacings were then tested by combining data from all spacings into a single regression equation for each year.

Spacing comparisons were made by setting up orthogonal linear and quadratic components of the combined data as additional variables, and making the appropriate F-tests. The linear component tested the hypothesis that there was no difference between the 6 x 6 and 15 x 15 spacings. The quadratic component tested the hypothesis that the 8 x 8 spacing did not differ from the average of the other two. Additional variables were set up as interactions of linear and quadratic terms with each of the environmental variables. These interactions tested the hypotheses with respect to each of the variables.

Fifteen independent variables were selected for initial analysis. These variables, tabulated below, were chosen from scatter diagrams of diameter growth rate plotted over each of the environmental factors.

Diameter growth variables

1957 and 1958

Y = Mean daily diameter growth rate in 0.001 inch for the 7-day period prior to a soil sampling date.

X_1 = Block effect = Block A minus Block B.

X_2 = Available water = The summation of the five sampling depths of the available water in inches divided by depth in inches.

X_3 = Average daily maximum air temperature for 7 days prior to a soil sampling date.

X_4 = $(X_3)^2$

X_5 = Average daily minimum air temperature for 7 days prior to a soil sampling date.

X_6 = $(X_5)^2$

X_7 = Sum of the rainfall occurring during the 14 days prior to a soil sampling date.

X_8 = Average daily maximum vapor pressure deficit for 7 days prior to a soil sampling date. (Calculated from relative humidity data.)

X_9 = Seasonal effects = The day number from January 1 on which a given soil sample was taken.

X_{10} = $(X_9)^2$

1958 only

X_{11} = Average daily evaporation in inches for 7 days prior to a soil sampling date.

X_{12} = Average daily wind in miles per day for 7 days prior to a soil sampling date.

X_{13} = Average daily mean soil temperature at a depth of one-half inch for 7 days prior to a soil sampling date.

X_{14} = Average daily mean soil temperature at a depth of 6 inches for 7 days prior to a soil sampling date.

X_{15} = Average daily mean soil temperature at a depth of 24 inches for 7 days prior to a soil sampling date.

RESULTS

Environmental Factors

Spring moisture was higher on all plots in 1958 than in 1957. Except for short drying periods in early July and late August, available water in the profile generally exceeded 4 inches throughout 1957 in all spacings (fig. 1). Moisture was high in March and April of 1958, with 7 to 9 inches of available water. There was a gradual decrease during the remainder of the season as the profile approached a low of about 3 inches in October. At no time during the study was moisture in the entire profile reduced to the wilting point. Physical properties and moisture characteristics of the soils are presented in table 1.

Normal growing season rainfall (March - October) for the experimental forest is 33.58 inches. Rainfall was 5.30 inches above normal in 1957, and 3.75 inches below normal in 1958. Trends of the other environmental factors are presented in figure 2.

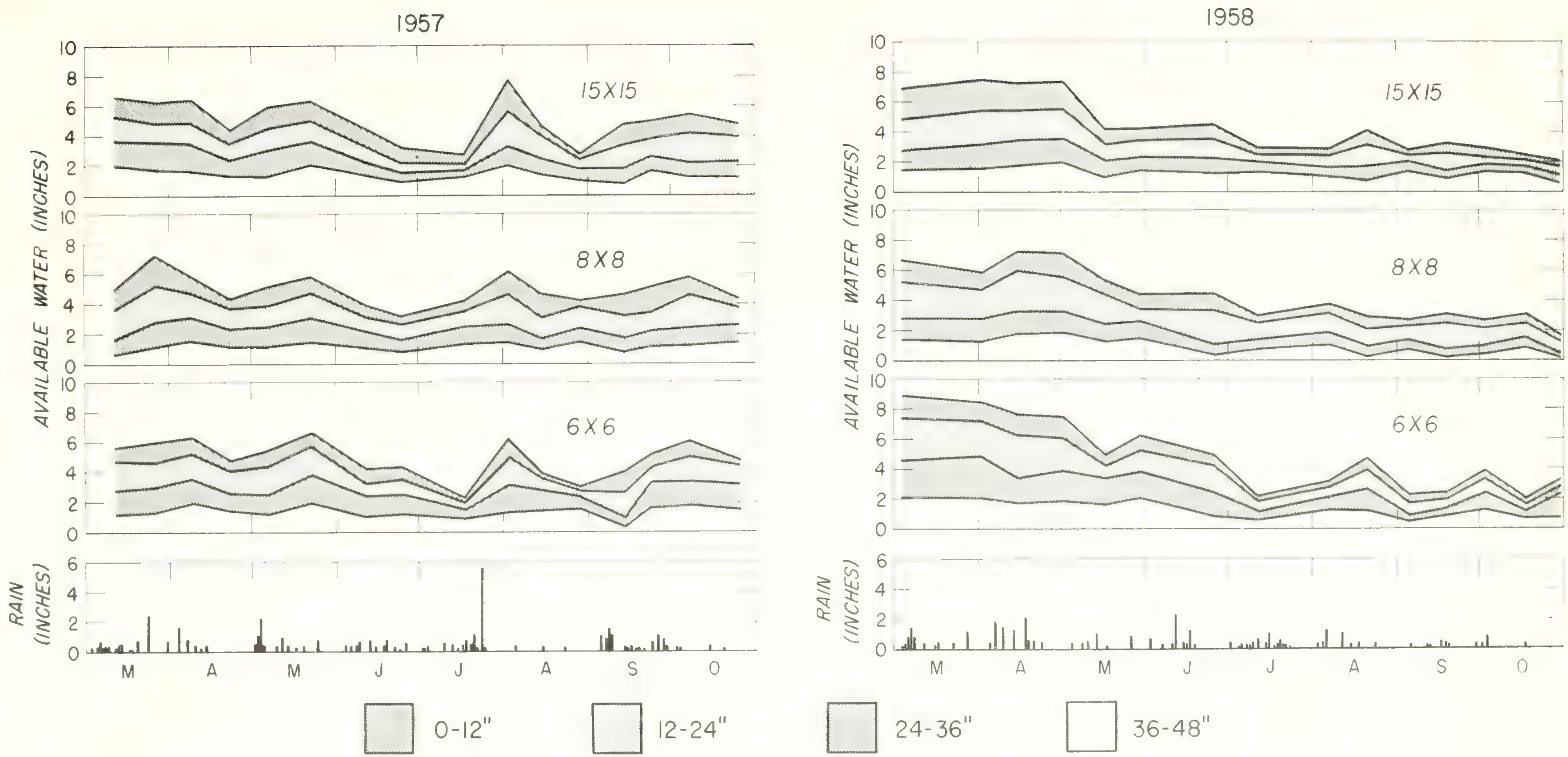

Figure 1.--Seasonal soil moisture curves by spacing and year showing rainfall and available water by 12-inch depths for the first four feet of soil.

Table 1.--Some physical properties of the soils on the study plots

Plot	Depth	Texture[1/]	Bulk density	Moisture content in atmosphere tension of--		
				0.06	0.3	15.0
	Inches			- - - - - - - Inches - - - - - - -		
A 6 x 6	0 to 6	LS	1.49	1.09	0.30	0.13
	6 to 12	LS	1.59	.87	.34	.13
	12 to 18	LS	1.61	1.26	.41	.18
	30 to 36	SCL	1.79	1.62	1.22	.87
	48 to 54	SCL	1.79	1.56	1.16	.84
B 6 x 6	0 to 6	LS	1.51	.87	.33	.10
	6 to 12	LS	1.56	1.24	.35	.12
	12 to 18	LS	1.59	1.05	.37	.13
	30 to 36	SCL	1.74	1.54	1.01	.68
	48 to 54	SC	1.72	1.67	1.56	1.10
A 8 x 8	0 to 6	LS	1.46	.95	.32	.11
	6 to 12	LS	1.60	.72	.39	.16
	12 to 18	SL	1.63	1.18	.72	.40
	30 to 36	SC	1.59	2.07	1.79	1.19
	48 to 54	SC	1.68	2.19	2.15	1.41
B 8 x 8	0 to 6	LS	1.47	1.28	.32	.11
	6 to 12	LS	1.61	1.05	.36	.16
	12 to 18	SL	1.62	.97	.53	.30
	30 to 36	SC	1.62	1.95	1.49	1.08
	48 to 54	SCL	1.79	1.82	1.51	1.05
A 15 x 15	0 to 6	S	1.53	.82	.27	.09
	6 to 12	S	1.63	.67	.30	.12
	12 to 18	LS	1.62	.59	.30	.12
	30 to 36	SC	1.72	1.68	1.62	1.22
	48 to 54	SC	1.79	1.73	1.64	1.17
B 15 x 15	0 to 6	LS	1.64	.89	.60	.22
	6 to 12	SL	1.63	1.52	.82	.38
	12 to 18	SCL	1.60	1.62	1.24	.77
	30 to 36	C	1.72	1.95	1.93	1.43
	48 to 54	SC	1.73	1.94	1.72	1.11

1/ S = Sand; C = Clay; L = Loam.

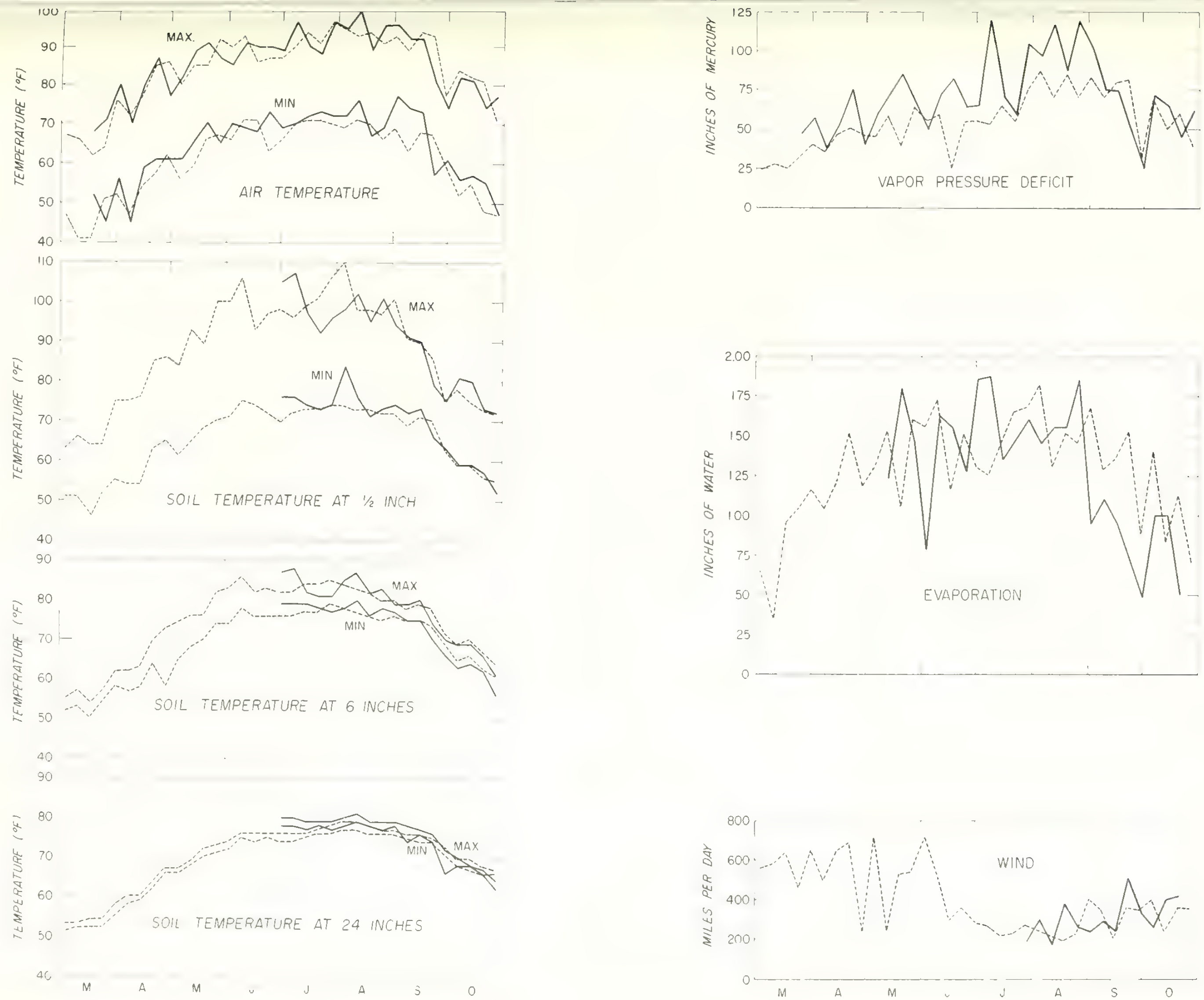

Figure 2.--Seasonal trends of the environmental factors measured in 1957 (———), and 1958 (-------).

Growth

Diameter growth in 1957 was somewhat unusual in that the curves were linear rather than the usual sigmoid type (fig. 3). High rainfall and soil moisture, especially during the summer, may account for this. Lack of the sigmoid relation also may be due in part to failure to start measurements early enough in the season. Growth during 1958 followed the sigmoid pattern quite well, with a slow increase in the spring, and a period of rapid growth in early summer, followed by a gradual decline in late summer and fall. Except for the last week or two in the fall, all spacings made measurable growth throughout both growing seasons.

In 1957, 75 percent of the growth of the 6 x 6 spacing was completed in early August. In 1958, 75 percent of the growth was completed by early June. The 8 x 8 and 15 x 15 spacings completed 75 percent of the growth by late August in 1957. In 1958, these spacings had completed 75 percent of their growth by late June and mid-July, respectively.

Average diameter of sample trees in each plot at the beginning of each season, together with average growth, is shown in table 2. Basal area in square feet per acre and basal area growth are shown in table 3. On the basis of average growth per tree, the relationship between basal area and spacing is the same as that of diameter growth. The trend is reversed on the acre basis.

Statistical Analysis

Analysis of variance of individual regression equations for 1957 showed that available moisture accounted for most of the variation in growth rate of the 6 x 6 and 15 x 15 spacings, and rainfall accounted for most of the variation in the 8 x 8 spacing. Of the remaining variables, only air temperature and seasonal effects were significant.

In 1958, available moisture again accounted for most of the variation in growth of the 6 x 6 and 15 x 15 spacings, and rainfall for most in the 8 x 8 spacing. Evaporation was the second variable removed; it was significant in the 6 x 6 and 15 x 15, but not in the 8 x 8 spacing. Maximum air temperature was third in order of significance in the 6 x 6 and 8 x 8 spacings, and block effect in the 15 x 15 spacing. Seasonal effects were removed last.

There are a number of reasons for nonsignificance of so many of the variables. Foremost probably are large measurement and sampling errors in growth and soil moisture observations. In such a situation variables must be strongly correlated and cover a wide range of values to show statistically significant relationships. Because of the uniformity of the climate most of the variables had few observations at their extremes. In addition, many of the variables were so highly intercorrelated that, in removing the effect of one or two of them, the effect of those remaining was also removed.

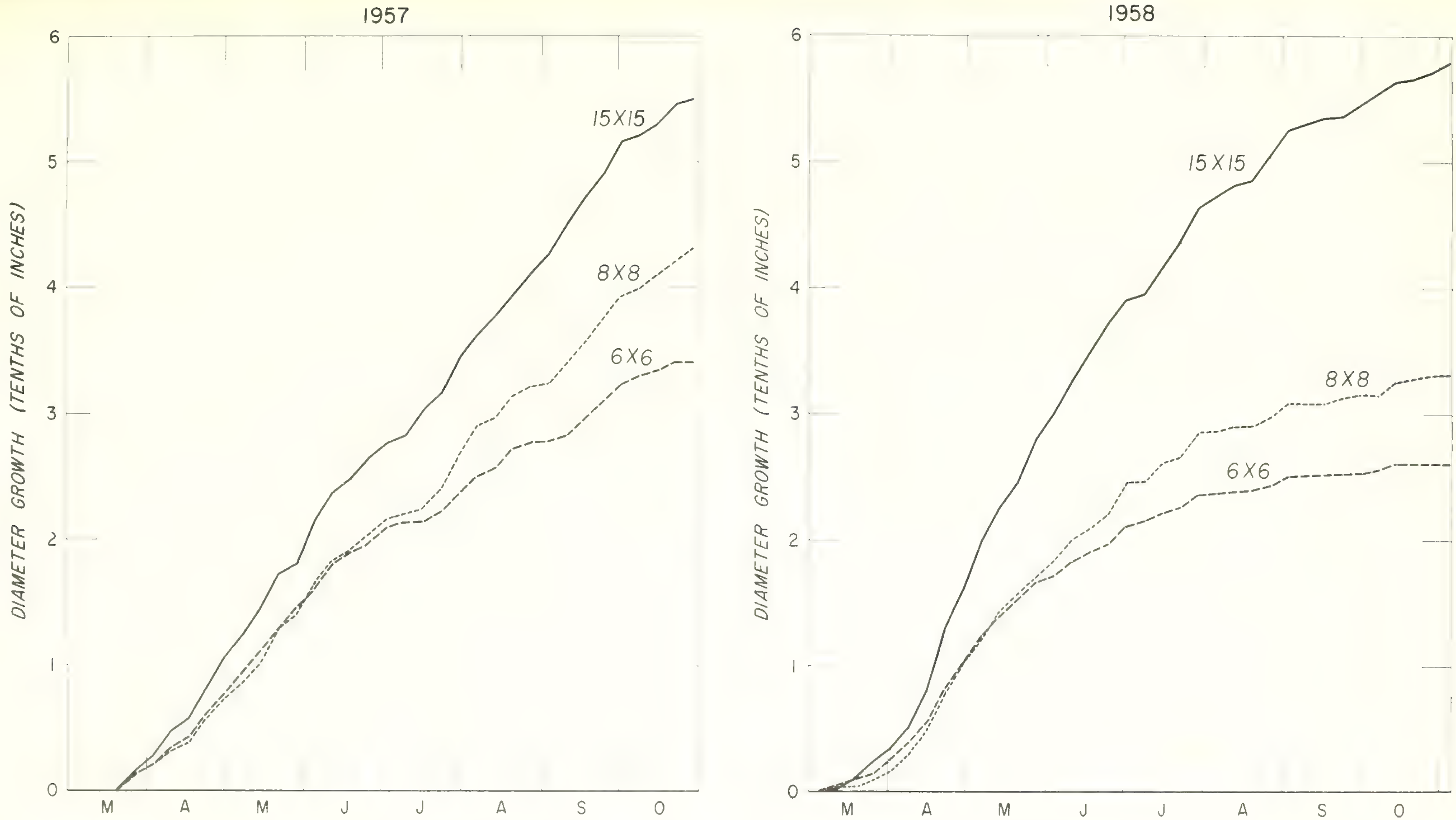

Figure 3.--Weekly cumulative diameter growth by spacing for 1957 and 1958.

Table 2.--Average initial diameter and average diameter growth of the sample trees on the study plots in 1957 and 1958

Plot	Trees per acre	1957		1958	
		Initial diameter	Diameter growth	Initial diameter	Diameter growth
		- - - - - - - - - - - - - Inches	- - - - - - - - - - - - -		
A 6 x 6	1,210	2.39	0.32	2.82	0.24
B 6 x 6	1,210	2.56	.37	3.07	.29
A 8 x 8	681	2.69	.40	3.19	.32
B 8 x 8	681	2.59	.46	3.17	.34
A 15 x 15	194	3.00	.49	3.59	.57
B 15 x 15	194	3.11	.62	3.79	.59

Table 3.--Initial basal area and basal area growth in square feet per acre on the study plots in 1957 and 1958

Plot	Trees per acre	1957		1958	
		Initial basal area	Basal area growth	Initial basal area	Basal area growth
		- - - - - - - - - - - - - Square feet	- - - - - - - - - - - - -		
A 6 x 6	1,210	37.86	10.63	52.61	9.26
B 6 x 6	1,210	43.89	13.62	62.73	12.60
A 8 x 8	681	27.06	8.63	38.08	8.12
B 8 x 8	681	25.13	9.79	37.44	8.49
A 15 x 15	194	9.61	3.43	13.78	4.78
B 15 x 15	194	10.33	4.48	15.28	5.22

In combining the data for spacing comparisons, variables were chosen from the individual regressions that were significant in at least two of the spacings. For 1957, those chosen were available water, maximum air temperature and its square, and season and its square. The same variables were chosen for 1958 with the addition of evaporation. The linear and quadratic contrasts were added last.

Analysis of variance showed that the environmental variables as well as the linear spacing contrast were highly significant both years, whereas the quadratic spacing contrast and the interactions of linear and quadratic contrasts with the environmental variables were not significant. Significance of the linear and nonsignificance of the quadratic contrast indicates that the relationship between diameter growth and spacing did not differ significantly from a straight line. This is substantiated by Bennett's (1) analysis of diameter growth of the spacing study as a whole. Nonsignificance of interactions of linear and quadratic contrasts with environmental factors indicated that effects of soil moisture, temperature, evaporation, and seasonal effects did not vary from spacing to spacing.

Equations for estimating diameter growth rate were calculated from the regression analyses of data for combined spacings. The equation for 1957 accounted for 57 percent of the variation in growth. The equation for 1958, differing only by addition of a variable expressing evaporation effects, accounted for 75 percent of the variation. Solutions provided an equation for each spacing for each year. Regression coefficients and their standard errors are given in table 4.

Table 4.--Regression coefficients and their standard errors for the diameter growth equations

Variable	1957		1958	
	Coefficient	Standard error	Coefficient	Standard error
6 x 6 constant	-41.595220	±9.295893	-44.871163	±9.634372
8 x 8 constant	-41.247577	±9.293614	-44.314519	±9.631927
15 x 15 constant	-40.809934	±9.292520	-43.757875	±9.630725
Available water	6.305105	±1.185600	6.102107	±1.408270
Evaporation	--	--	1.418635	± .468043
Max. air temp.	.999377	± .223824	1.062768	± .244126
(Max. air temp.)^2	- .005634	± .001338	- .007299	± .001500
Season	- .008719	± .001384	.069350	± .017378
(Season)^2	--	--	- .000187	± .000042

DISCUSSION

Growth

It is apparent from these data that differences in diameter growth from spacing to spacing cannot be attributed to measured environmental factors. Although the 15 x 15 grew several weeks longer than the 6 x 6 and 8 x 8 spacings, the nonsignificance of the interaction of spacing and available water indicates that even the effect of moisture on growth did not vary with spacing.

Available water in the profile was adequate for growth throughout most of the study period, dropping to a low of 3 inches only toward the end of the 1958 season. A separate analysis of the soil moisture data showed that moisture was about the same in the 6 x 6 and 15 x 15 spacings, and somewhat higher in the 8 x 8.[1/] It is likely that root competition had not yet become an important factor, even in the closest spacing. This apparent lack of competition, and a plentiful supply of moisture throughout most of both growing seasons, explains why spacing had no effect on the growth-soil moisture relations. Had there been long periods of severe moisture deficits, especially early in the year, differences in growth between spacings because of moisture might have been significant. The water deficit in the latter part of 1958 undoubtedly influenced growth, but its effect was general, in that growth of all spacings was retarded at about the same time. During the wet 1957 season growth was maintained well into late summer, almost two months longer than in 1958.

These results are not necessarily at variance with Zahner and Whitmore's (14) work in Arkansas where differences in diameter growth of thinned and unthinned loblolly pine plantations were associated with soil moisture as well as with crown and root development. The difference in growing season moisture regimes in the two areas is such that soil moisture becomes limiting much more often in south Arkansas than in middle Georgia. The average June-August rainfall in the coastal plain of Arkansas is 11.7 inches, evenly distributed among the 3 months (12). Extended dry periods occur almost every summer, and available water in the root zone frequently is reduced to near the wilting point by midsummer. Unless rain replenishes soil moisture, considerable growth losses occur (11, 13).

In contrast, summer droughts severe enough to cause noticeable growth losses are much less common in the middle coastal plain of Georgia. Average June-August rainfall is 15.4 inches, with almost half of it coming in July during the peak of the growing season (12). While dry periods do occur, they are of short duration. For this reason the influence of spacing on growth-soil moisture relationships can be expected to be much less pronounced in middle Georgia than in south Arkansas.

1/ Harms, W. R. A study of the effect of certain climatic factors on soil moisture and the growth of planted slash pine. Unpublished Ph. D. dissertation, Duke University. 1961.

If moisture were not limiting, growth differences between spacings must have been caused by some other factor. This factor probably was light. Other than soil moisture and perhaps mineral nutrients, it is the only important environmental factor whose influence is strongly, though indirectly, affected by spacing. Since growth of individual trees is conditioned by crown size, which is limited by mutual shading, growth differences between spacings were probably the result of differences in photosynthetic area. Growth and crown ratio measurements taken in 1958 support this assumption in that the 15 x 15 spacing with a crown ratio of 85.4 percent grew 50.3 percent more in diameter than the 6 x 6 with a crown ratio of 57.5 percent, and 43.1 percent more than the 8 x 8 with a crown ratio of 65.3 percent.

During the first 4 years of this plantation there was no difference in diameter growth among spacings. Differences first became apparent at the end of the fifth growing season at a density of 500 to 550 trees per acre (1). At that time the trees averaged 12.6 feet in height and competition for light was just beginning in the 8 x 8 and narrower spacings.

If growth per tree increases with crown surface, as measured by crown ratio, and therefore with spacing, it follows that on a stand or area basis growth also increases with crown surface. However, in this case crown surface on a stand basis is greater on the narrow spacings. This is borne out by the basal area growth data. Over the 2-year period of study basal area growth of the 6 x 6 spacing averaged 11.53 square feet per acre per year, the 8 x 8 spacing 8.76 square feet, and the 15 x 15 spacing 4.48 square feet.

Environmental Factors

The equations presented in table 4 make it possible to study the probable relationship between diameter growth and each of the environmental factors. Curves of diameter growth for each factor for the 8 x 8 spacing were obtained by holding all other variables at their mean value, and calculating growth as a function of the designated variable.

The curves in figure 4 show the average effect of each of the three significant environmental variables. The shapes of these curves should be regarded as general trends applicable only to the data at hand, although they probably approximate those that would be derived whenever similar climatic conditions prevail.

The shape of the available water and temperature curves support the results of past work (5, 6). Diameter growth increased linearly with available water over the range of moistures encountered in the study. Although it is not apparent, the rate of increase in diameter growth with available water was somewhat less in 1958 than 1957. This resulted from drier growing conditions in 1958. As shown in figure 3, growth continued at a high rate well into fall in 1957, but had slowed markedly by mid-July in 1958.

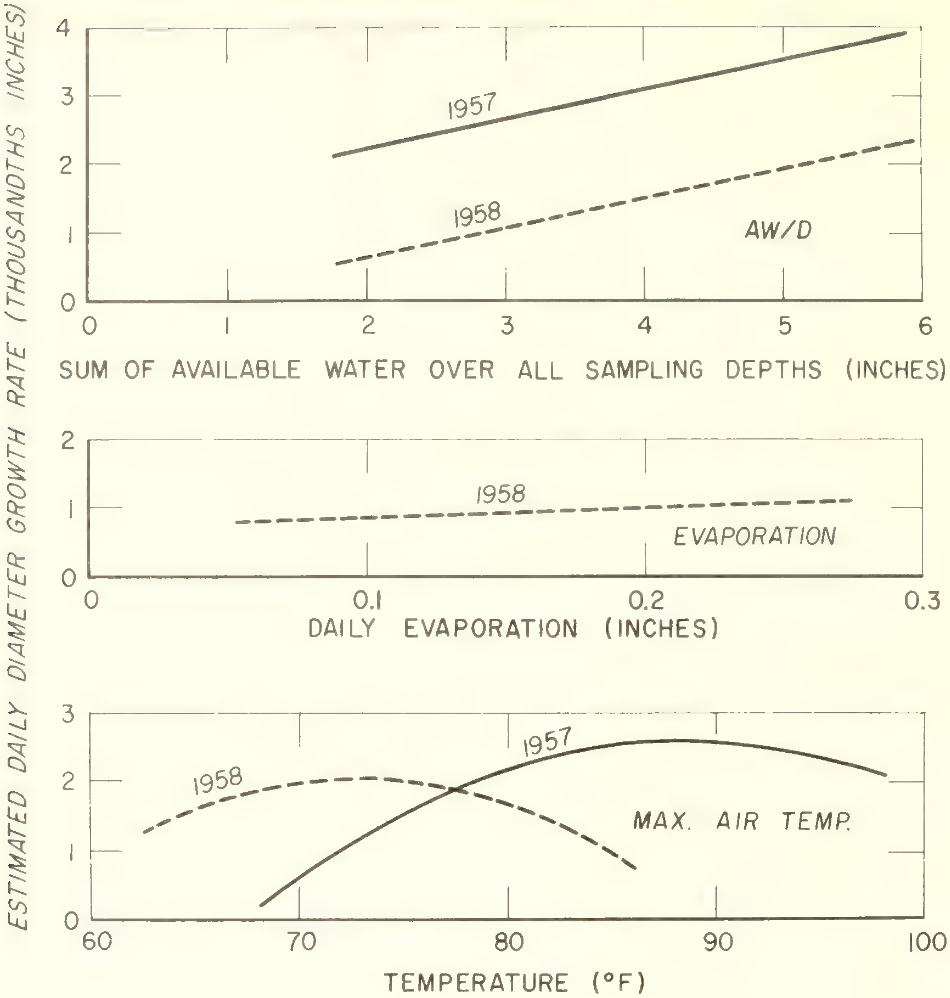

Figure 4.--Estimated daily diameter growth rate of the 8 x 8 spacing plotted over the several environmental factors with all other factors held at their mean. Each of the factors is designated by the symbols used in the regression equations.

In both years growth increased with maximum air temperature up to a certain point after which higher temperatures were accompanied by a progressive drop in growth. This effect was influenced by the relation between temperature, photosynthesis, and respiration. As temperature increases, photosynthesis soon reaches a maximum rate, under constant light conditions, while respiration continues to increase. The net effect is a decrease in food available for growth. In 1957 growth reached a maximum at a temperature of about 88° F. In 1958 the maximum was 73° F. The rate of growth increased more rapidly with temperature in 1957 than in 1958. The difference in general climatic conditions between the 2 years does not appear to be great enough to account for such a large drop in the temperature effect. It is likely that the difference in temperature effect was due to a temperature-soil moisture interaction. In 1957, water deficits were considerably less severe than in 1958. Evidently when the soil is moist, temperature can be higher before it becomes limiting to growth.

Growth was positively correlated with evaporation. The effect of evaporation on growth is expressed indirectly through its relation to the evaporating power of the air which in turn influences the rate of transpiration. Under conditions of high transpiration rates, absorption of water by the roots may lag behind water loss through the leaves even when soil moisture is adequate. This will result in a decrease in the turgidity of the cells, stomatal closure, and a reduction in the rate of photosynthesis. Any of these conditions will check growth.

It is surprising therefore that the analysis shows a positive relation between growth and evaporation. Possibly this situation can be explained by the fact that high evaporation rates occur on bright, sunny days, a condition which favors growth if moisture is not limiting. Also, there is a strong correlation between evaporation and temperature, because both factors tend to increase together.

SUMMARY AND CONCLUSIONS

Multiple regression methods were used to study the influence of plantation spacing on the relationships between certain environmental factors and the diameter growth of young slash pine in the middle coastal plain of Georgia.

The study was made during the sixth and seventh growing seasons in a plantation planted at spacings of 6 x 6, 8 x 8, and 15 x 15 feet. Diameter growth was measured weekly and soil moisture at 2- to 3-day intervals. Soil and air temperature, relative humidity, evaporation, wind, and rainfall measurements were made at a weather station installed near the plantation.

Significant correlations were found between diameter growth and available soil moisture, maximum air temperature, evaporation, and elapsed days from January 1. None of these factors explained the differences in diameter growth between spacings. Differences were attributed to the interaction of light and photosynthetic surface. Photosynthetic surface of the trees, as measured by crown ratio, increased with spacing; under the same light conditions individual trees on the wide spacing produced more food for growth than those on the close spacing.

Whereas competition for light had begun in the close spacing during the fifth year, root competition, and therefore competition for soil moisture, was not yet apparent during the sixth and seventh years. The rate of change of diameter growth with change in soil moisture was uniform for all spacings.

The growing season moisture regime of the middle coastal plain of Georgia is such that soil moisture probably is not a very serious limiting factor in plantations at this age even at close spacings, though it may become important as the stand develops.

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Management of Small Woodland Holdings in the Georgia Piedmont

-A 12-Year Report-

by

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Management of Small Woodland Holdings in the Georgia Piedmont

- A 12-Year Report -

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R. M. Romancier and E. V. Brender

Trees can be a crop, just as cotton, corn, and pecans are a crop. Trees, however, differ from annual crops in that all along they reach maturity for one product or another, and some trees can always be left to grow and increase in value. For example, the trees on a 38-acre woodlot on the Hitchiti Experimental Forest were worth $2,315 in 1948. During a 12-year period $1,920 worth of trees were harvested, and those left standing are now worth $7,065.

No special tools were used, no fertilizer, no irrigation; just a reasonable outlay of energy, a small amount of money, and above all a little planning ahead and deciding which trees to harvest and which to keep. This same thing could be done by any small woodland owner on most 30-, 40-, and 100-acre tracts of timberland.

Over 90 percent of the commercial forest land in central Georgia is in private ownership, mostly in small farm holdings. 1/ The greatest portion of this forest acreage is not under planned management and contributes only a fractional share of its potential to the owner and to the economy of the region.

To show that these small holdings could be profitably managed, three farm woodlots were taken under management on the Hitchiti Experimental Forest in 1948. This forest, located in the lower Piedmont of middle Georgia, is typical of many of the woodlands of the region. In the three woodlots, the mixed loblolly-shortleaf pine stands were put under management to produce continuous crops of sawtimber and pulpwood. This paper is the story of how hitherto unmanaged, relatively young stands of pine trees were changed into valuable woodland holdings.

1/ Anonymous. Preliminary Forest Survey statistics for central Georgia, 1961. U. S. Forest Serv. Southeast. Forest Expt. Sta. 1961.

A mature, good-quality sawtimber tree in Farm Woodlot 1. At 49 years of age, this tree is 24 inches d. b. h. and contains 600 board feet, worth at least $18 on the stump.

THE HITCHITI FARM WOODLOTS

A large portion of the lower Piedmont of Georgia was originally in oak-hickory forests. Following settlement of this region by the white man, the land was repeatedly cleared and abandoned. Pines generally became established on the abandoned land and the principal upland forest type is now a mixture of loblolly and shortleaf pine, often with a moderate to dense understory of hardwood species.

As a first step in planned management of the three woodlots, a survey was made to determine the acreage in each woodlot, the age classes of the stands (table 1), numbers and sizes of trees, and sawtimber and pulpwood volumes (table 2). The most valuable woodlot, Farm Woodlot 1, had a higher proportion of older pine stands than the other woodlots. Stands over 50 years old made up 12.4 percent of the area in Farm Woodlot 1, compared to 5.9 percent in Farm Woodlot 2, and none in Farm Woodlot 3.

Table 1. --Stand age distribution by woodlots, 1948

Age class	Farm Woodlot 1 39.5 acres	Farm Woodlot 2 49.0 acres	Farm Woodlot 3 38.2 acres	All woodlots 126.7 acres
	- - - - - - -	- - - Percent	of area - - -	- - - - - - -
Open land	5.6	5.1	--	3.7
Trees less than 25 years old	44.8	48.6	67.0	52.9
Trees 25 to 50 years old	37.2	40.4	33.0	37.2
Trees 50 years old or older	12.4	5.9	--	6.2
Total	100.0	100.0	100.0	100.0

Table 2. --Initial stand, 1948

(per acre)

Woodlot	Area	Average site index	Trees	Average d. b. h.	Volume		
					Sawtimber	Pulpwood	Total
	Acre	Feet	Number	Inches	Board feet	- - Cubic	feet - -
Farm Woodlot 1	39.5	80	88.9	11.2	7,416	368	1,957
Farm Woodlot 2	49.0	86	64.2	10.9	4,569	289	1,282
Farm Woodlot 3	38.2	89	75.1	9.8	3,001	348	1,015

Farm Woodlot 1 has the most favorable topography for pine of the three areas; it consists of gentle to moderate upper slopes and only a small area of lower slopes. Hardwoods are less of a problem here than on the other two woodlots. In Woodlot 1 the age classes and stocking were not in balance for sustained yield, but the area contained a large volume of pine, with 7,416 board feet 2/ plus 4.6 cords 3/ of pulpwood, or a total of 1,957 cubic feet of pine per acre.

Farm Woodlot 2 was less heavily stocked with pine than Farm Woodlot 1, but was still considerably above the level of an average middle Georgia woodlot. At the start of the study, this woodlot had 4,569 board feet and 3.6 cords of pulpwood for a total of 1,282 cubic feet per acre.

2/ International $\frac{1}{4}$-inch rule.
3/ A cord is a volume of stacked wood 4' x 4' x 8'.

A young stand in Farm Woodlot 2, typical of many of the stand conditions when the study was started.

Farm Woodlot 3 had the lowest sawtimber volume of the three areas, and was more typical of an average small forest tract. It contained a large number of young trees with good future potential, with an average site index[4/] 10 feet higher than that of Woodlot 1. The pine sawtimber volume in Farm Woodlot 3 was 3,001 board feet and 4.4 cords of pulpwood to the acre, for a total of 1,015 cubic feet per acre.

Like other 40-acre forest tracts in middle Georgia, the Hitchiti farm woodlots are not all pine stands; hardwood stands are also present (fig. 1). In Farm Woodlot 1 the hardwoods occur principally as an understory, but in Farm Woodlots 2 and 3 hardwood stands occupy 39 and 45 percent of the area, respectively. However, one-fourth of the hardwood area is capable of growing fine hardwood timber. The other areas support a mixture of pine and mostly cull hardwoods.

4/ Height of the larger, taller trees in each stand at a certain age, usually 50 years.

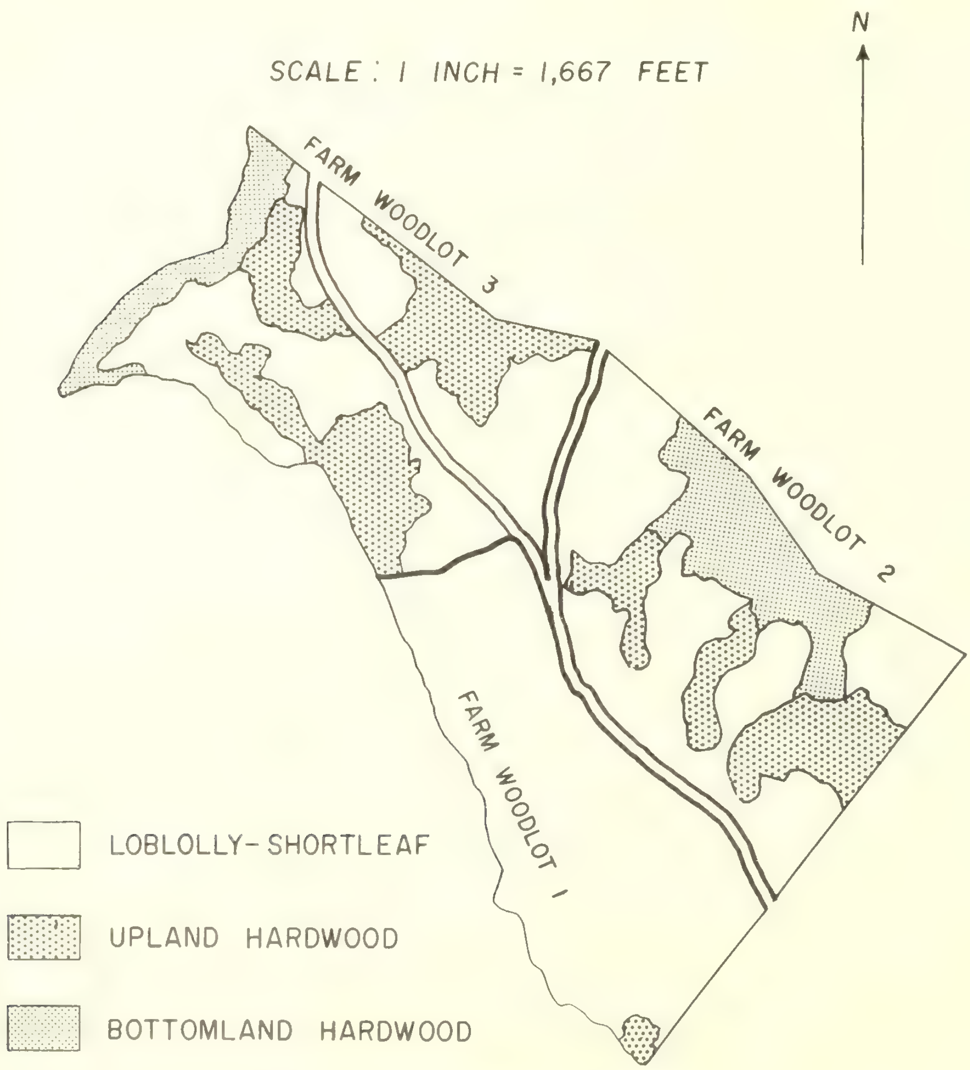

Figure 1.--The Hitchiti farm woodlots.

MANAGEMENT METHOD

Harvesting of the tree crop on the three woodlots has been under a system of partial cuts, removing surplus and mature trees, and leaving others to increase in size and value. The system as carried out provides a steady supply of wood for as many years as the woodlot manager wishes. Harvests may be made annually or periodically. In this study, all the early cuts were improvement cuts, removing the large, rough trees, defective trees, and trees that stood too crowded. Some trees were harvested each year in each woodlot. Later some groups of mature, sawtimber-size trees were cut, and some sawtimber stands were cut rather heavily, leaving about 25 well-formed and well-spaced seed trees per acre to regenerate a new stand. A few stands were thinned for pulpwood and one open-grown stand of loblolly pine was clear cut and planted. Farm Woodlot 2 was converted in 1953 to a periodic harvest schedule, so that the growth of several years could be cut at one time. In 1948, Woodlots 2 and 3 were understocked and quite out of balance in age and size classes for systematic harvesting of forest products. To get a sustained annual or short periodic yield you must cut less than the annual growth until the stand or forest is properly stocked with trees of the right sizes. Since growth data for the woodlots were not available, the allowable cut was based upon assumed board-foot growth rates as follows:

Farm Woodlot 1 - 300 board feet per acre per year

Farm Woodlot 2 - 150 board feet per acre per year

Farm Woodlot 3 - 75 board feet per acre per year

The allowable harvest cut for each woodlot was the assumed per-acre growth multiplied by the entire area in the woodlot. This volume was harvested annually from a portion of the area in each woodlot, rather than spreading the harvest over the entire woodlot. After the first repeat inventory in 1953, the allowable cut was adjusted on the basis of growth that the woods made during the first 5 years. However, not all of the growth was scheduled for cutting in Woodlots 2 and 3; some was left to build up the stocking.

To regulate and control management of these woodlots, total inventories were taken of the initial stands, and again of the entire woodlot at the end of 5 years of management, and 7 years later in 1960. Records have been kept by stands and summarized for each woodlot. All trees 6 inches d. b. h. and larger were measured and merchantable heights estimated to a 4-inch top for pulpwood and to an 8-inch top for sawtimber which included trees 9.6 inches d. b. h. and larger.

HARVESTS

Over the 12-year period, 330,667 board feet and 120.4 standard cords of pulpwood have been cut from the three woodlots, with a cash stumpage value of about $10,000.

Local markets for sawtimber and pulpwood were readily available. Stumpage prices have fluctuated widely, but have generally increased with time (table 3). These are prices that a small-scale timber grower would also have expected from the sale of marked pine sawtimber and pulpwood. The amount, quality, and location of the wood will affect the price, as will market conditions.

Table 3. --Pine stumpage prices

Year	Sawtimber	Pulpwood
	Dollars per M	Dollars per cord
1949	18.13	1.50
1950	21.93	1.88
1951	29.02	2.25
1952	30.32	2.70
1953	31.69	3.00
1954	23.80	3.40
1955	23.40	3.70
1956	25.60	4.20
1957	28.20	4.80
1958	28.60	4.94
1959	29.20	5.25
1960	35.20	5.60

A record of the amount of wood removed from each woodlot was kept (table 4). The annual per-acre harvest from Farm Woodlot 1 amounted to 300 board feet and 0.1 cord of pine; in Farm Woodlot 2 it amounted tc 194 board feet and less than 0.1 cord, and in Farm Woodlot 3, 131 board feet and 1.4 cords of pine were cut annually. The average yearly harvest of Woodlots 2 and 3 exceeded the originally planned annual harvest because the reinventory made in 1953 showed that the growth in these two woodlots was considerably better than had been expected.

In each woodlot, the sawtimber trees cut averaged 16 inches d. b. h. In some of the stands, no sawtimber was cut; in others, no pulpwood was cut. Four upland hardwoods areas, totaling 10.6 acres, were not cut at all.

Table 4. --Harvests made over a 12-year period

(per acre)

Woodlot	Operations	Trees	Average d. b. h.	Volume		
				Sawtimber	Pulpwood	Total
	Number	Number	Inches	Board feet	- - Cubic feet - -	
Farm Woodlot 1	10	25.0	13.6	3,595	103	903
Farm Woodlot 2	6	10.0	15.8	2,325	35	528
Farm Woodlot 3	10	23.0	12.0	1,568	139	482

The truck holds about 3 cords of pulpwood, worth about $16.80 on the stump, $28.80 at roadside, and $45.90 delivered at a woodyard.

About 1,500 board feet of sawtimber, worth $45 on the stump.

PRESENT CONDITION OF THE WOODLOTS

A great deal has happened to the farm woodlots in 12 years (table 5). The large, rough sawtimber trees have been cut, surplus trees in certain size classes have been removed, slow growers and defective trees have been harvested, some cull hardwoods deadened, and the growing space for trees has been improved; some trees have been allowed to grow into larger, more valuable size classes, for one large sawtimber tree is typically worth several small ones. To illustrate, a 10-inch (d. b. h.) loblolly pine with one 16-foot log contains about 33 board feet, worth about 99¢ on the stump. A 14-inch (d. b. h.) tree with three 16-foot logs contains 180 board feet and is worth about $5.40 stumpage.

The changes that took place are illustrated in figures 2a and 2b. In all three woodlots the number of pulpwood size trees increased. In Woodlot 1 there was a slight decrease in sawtimber trees, but in Woodlots 2 and 3 sawtimber size trees increased in number. In terms of cubic feet, the changes are parallel to changes in tree numbers, except that in Woodlot 1, the total volume has not changed during the 12 years. The other two woodlots gained in volumes in all product size classes, with the largest gains in the small to medium sawtimber size class in Woodlot 3. These gains reflect primarily the high proportion of young pine stands that have grown into merchantable size during the 12-year period. Board-foot volume changes followed the same pattern, as shown in the following tabulation:

	Per acre board-foot volume	
(Woodlot)	(1948)	(1960)
1	7,416	6,572
2	4,569	5,681
3	3,001	5,206

The decrease in Woodlot 1 resulted from cutting large overmature trees.

Table 5. --Present stand, 1960

(per acre)

Woodlot	Trees	Average d. b. h.	Volume		
			Sawtimber	Pulpwood	Total
	Number	Inches	Board feet	- - Cubic feet - -	
Farm Woodlot 1	110.9	10.1	6,572	515	1,935
Farm Woodlot 2	79.0	10.9	5,681	389	1,619
Farm Woodlot 3	88.8	10.4	5,206	425	1,570

Figure 2a.--Number of pulpwood, small sawtimber, and large sawtimber trees (per acre).

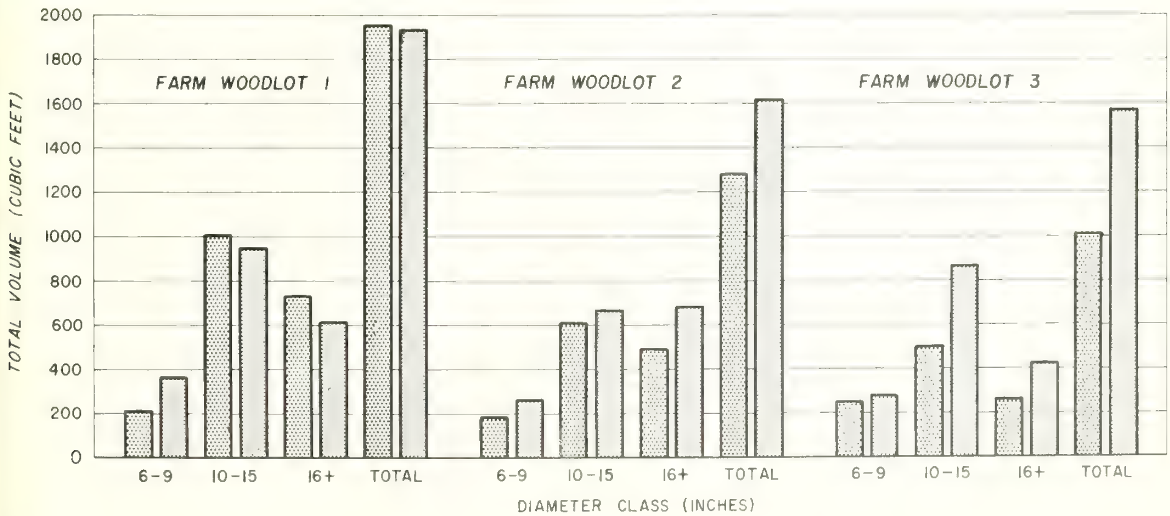

Figure 2b.--Cubic-foot volume in pulpwood, small sawtimber, and large sawtimber trees (per acre).

Just as an agricultural crop must compete with many weeds for its water, nutrients, and living space, so pines compete with hardwoods for these same essentials. In the pine stands where harvests were made, hardwood control measures were undertaken to eliminate large cull hardwoods and some understory hardwoods that interfered with pine regeneration. But by and large no efforts were expended toward converting the hardwood areas to pine. Hardwood trees of cordwood size increased in all three woodlots. However, one-fourth of the hardwood area supports commercial species of good quality and will contribute to the revenue from the woods. The remainder should be converted to pine. Now that prospects for selling pulpwood from hardwoods are in sight, conversion to pine may be accomplished, if not at a profit, at least at reasonable costs.

PRODUCTION

The amount of wood present in 1960, less the wood present when the study began in 1948, plus the wood harvested between 1948 and 1960 is the production of the woodlots. Table 6 gives the production of each woodlot in terms of total cubic feet and in board feet of sawtimber and standard cords of pulpwood. Dollar values are also given for the initial amount of wood, wood harvested, wood remaining, and wood produced. The average annual production for the three woodlots has amounted to $15.49 per acre.

The forest owner has been able to build substantially on his investment over the past 12 years. At the same time he has received a sizeable annual income. The woodlots in their initial condition in 1948 were worth about $97 per acre; $77 worth of wood has been harvested per acre, based on the rates actually paid. The present value of the woodlots is about $205 per acre.

While these are returns only, and do not include the cost of items such as taxes, fire protection, equipment, or labor for marking trees or deadening hardwoods, these dollar values do indicate reasonable returns that a landowner might expect under similar conditions.

Table 6a. --12-year production of wood on the farm woodlots (per acre)

Woodlot	Initial	Harvested	Residual	Production
	Cubic feet			
Farm Woodlot 1	1,957	903	1,935	881
Farm Woodlot 2	1,282	523	[illegible]	[illegible]
Farm Woodlot 3	1,015	482	1,570	1,037

Table 6b. --12-year production of forest products on the farm woodlots (per acre)

Farm Woodlot	Initial		Harvested		Residual		Production	
	Board feet	Cord-wood	Board feet	Cord-wood	Board feet	Cord-wood	Board feet	Cord-wood
Farm Woodlot 1	7,416	4.60	3,595	1.29	6,572	6.44	2,751	3.13
Farm Woodlot 2	4,569	3.61	2,325	.44	5,681	4.86	3,437	1.69
Farm Woodlot 3	3,001	4.35	1,568	1.74	5,206	5.31	3,773	2.70

Table 6c. --12-year production of the farm woodlots in dollars per acre

Woodlot	Initial		Harvested		Residual		Production		
	Board feet 1/	Cord-wood 1/	Board feet 2/	Cord-wood 2/	Board feet 3/	Cord-wood 3/	Board feet	Cord-wood	Total production
Farm Woodlot 1	134.45	6.90	100.03	4.64	197.16	36.06	162.74	33.78	196.52
Farm Woodlot 2	82.84	5.42	74.01	1.94	170.43	27.22	161.60	23.74	185.34
Farm Woodlot 3	54.41	6.52	44.18	6.28	156.18	29.74	145.95	29.50	175.45

1/ $18.13 per MBM and $1.50 per cord.
2/ Value prorated on basis of prices paid from 1949 to 1960.
3/ $30.00 per MBM and $5.60 per cord.

SUMMARY

Three woodlots representing many of the stand and site conditions found in small woodland holdings in middle Georgia have been under sustained-yield management for a period of 12 years. They have been managed much as a small woodland owner might do, applying good forestry practices and working to promote proper stocking and good growth.

The objectives have been a continuous yield of saw logs and pulpwood on an annual cutting cycle. The annual cut was set below the estimated annual growth to build up the initial stocking.

Harvesting operations were at first strictly improvement cuts and began early in 1949. Harvests were made annually in each woodlot through 1956, except in Farm Woodlot 2, which was converted in 1953 to a periodic harvest schedule.

Over the 12-year management period, an amount of wood equal to about half the 1948 cubic-foot volume was harvested from each woodlot. In other words, a large amount of wood was removed, but the residual stocking remained the same or was improved over the initial stocking.

The actual financial returns from the woodlots have been considerable, averaging $77 per acre. There has also been a significant increase in the value of each woodlot. Comparing the initial and production values of the three woodlots, the compound interest rates earned are:

Farm Woodlot 1	2.6 percent
Farm Woodlot 2	6.4 percent
Farm Woodlot 3	9.2 percent

A portion of the increase in valuation is the result of the general business inflation, but much of the increase is directly related to the forest management practices used.

A great many of the small woodland holdings in middle Georgia can be profitably managed for wood production. Initial investments are small while the potential returns are great.

The sustained yield of saw logs and pulpwood, as described for this study, is only one of the ways in which farm woodlots in middle Georgia can be handled. For help in selecting and applying the most suitable management plan, a Consulting Forester, Farm Forester, or a State Extension Forester can provide guidance and advice.

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Pretreating Turpentined Longleaf Pine Poles to Improve Penetration and Retention of Creosote

by

Rufus H. Page

and

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U.S. Department of Agriculture - Forest Service
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PRETREATING TURPENTINED LONGLEAF PINE POLES TO IMPROVE PENETRATION AND RETENTION OF CREOSOTE

by

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and

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In former times, when deep chipping was the standard method of turpentining, the lower part of the butt log in a harvested slash or longleaf pine containing the scars of turpentine faces was usually cut off or "jump-butted." This meant the loss of much potentially valuable wood, often a clear bolt 6 or 8 feet long.

In modern methods of turpentining, the bark hack cuts little if any deeper than bark thickness, and thus the round butt log (most valuable part of the tree) is sometimes used in its entirety as a pole after the tree has been "worked-out" as a gum producer. However, in some cases, trouble with penetration of preservatives in the pitch-soaked lower section behind the turpentine face has been encountered, and American Standards Association Specification No. 05.1-1948, Paragraph No. 2.4.5 for Wood Poles states, "No pole shall have a scar or turpentine face within two feet of the ground line." The ground line of poles varies with pole length. For example, for a 20-foot southern pine pole, the ground line is 4 feet from the butt; for a 50-foot pole, 7 feet; for an 80-foot pole, 10 feet. The scar, then, is usually well below the ground line in long poles made from trees that were worked only 3 or 4 years. However, in short poles and poles from trees turpentined for longer periods, there may be less than 2 feet of unscarred wood between the ground line and the face, making it necessary to remove all or part of the scar.

While jump-butts or scar-faces are sometimes sold for products such as fence posts, kindling, and pulpwood, the value of this portion of the tree is usually greater as part of a pole. This is why both the timberland owner and the treating plant operator lose when potential pole timber has to be jump-butted.

In 1961 there were about 40 treating plants in the South affected by turpentining. It is estimated that perhaps 40 more will buy worked-out turpentined poles in the next several years because of a revitalized interest in naval stores in Texas, Oklahoma, Louisiana, and Mississippi.

One treating company reports that usually from 30 to 36 inches of the butt has to be removed when it is necessary to jump-butt trees to comply with American Standards Association specifications, and that the value of the pole is reduced on the average of about one dollar. For example, if a 40-foot class 5 pole is shortened to a 35-foot class 4 pole, the value, based on current prices, drops from \$7.78 to \$6.64, or \$1.14. This same company treats about 50,000 worked-out turpentined poles each year, most of which have to be jump-butted, so in this case jump-butting results in a loss of roughly \$50,000 per annum. While these scar-faces do have a salvage value of 15 cents each to this company, the cost of jump-butting is about 10 cents per pole.

Most utility companies purchase poles on American Standards Association specifications and so do not accept poles when the scar-face is within 2 feet of the ground line. Scars near the ground line are not permitted for two reasons: (1) It is at and near the ground line that the pole is most seriously affected by decay; (2) it is generally believed that preservative penetration is unsatisfactory behind the scar-face. While cores could be taken from the face to appraise the treatment, this is not usually done because decay fungi might enter the pole through the borings even though the holes are plugged.

Several studies have been made to evaluate preservative treatment behind bark-chipped, acid-treated faces in both slash and longleaf pine. In 1948, Snow made penetration studies of test cores from a number of slash and longleaf poles with a history of 3 years of bark chipping and acid treatment.[1] These poles were given a standard 8-pound treatment at The Langdale Company, Valdosta, Georgia, after they were rossed. In the slash pine samples, preservative penetration behind the scar-faces was considered satisfactory, but penetration behind the scar-faces of longleaf poles was not satisfactory, except where the poles were incised. No reason for difference in penetration by species was given, although Snow suggested that there might be more dense pitch-soak behind the longleaf faces, since the longleaf poles grew more slowly than the slash poles.

A second study made at The Langdale Company in 1957 by the McCallum Inspection Company of Norfolk, Virginia, involved mixed slash and longleaf pine. The results were not published, but 30-day air-seasoned poles from worked-out turpentined trees showed insufficient penetration in 14.3 percent of the number treated with 12 pounds of creosote per cubic foot, in 20.3 percent treated with 10 pounds, and in 25.0 percent treated with 8 pounds. In freshly cut poles, insufficient penetration was found in 2.6 percent treated with 12 pounds and 5.8 percent treated with 10 pounds.

Because data from these studies showed erratic penetration, the need for a more thorough investigation of the problem was indicated, and in 1960 the Southeastern Station, in cooperation with the Georgia Forestry Commission

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1/ Snow, Albert G., Jr. Turpentining and poles. South. Lumberman 177 (2225): 276, 278-279. 1948.

conducted a third study to evaluate preservative treatment behind scar-faces of worked-out turpentined trees.[2/] This study was also made at The Langdale Company. Slash pine poles seasoned 30 and 90 days, steam conditioned at 259° F. for 12 hours, and given a 10-pound treatment, treated satisfactorily. Slash pine poles treated green after steaming, and slash pine poles seasoned 90 days and treated to 8 pounds per cubic foot retention, and longleaf pine poles seasoned 30 and 90 days and treated to 10 pounds per cubic foot retention, did not meet American Wood-Preservers' Association Specification C3. As of April 8, 1960, this specification required retention by assay in southern pine poles of 7 pounds per cubic foot for 10-pound gauge retention and 6 pounds per cubic foot for 8-pound gauge retention. This is now 7.5 pounds per cubic foot for 10-pound gauge retention.

In the two studies where the poles were segregated by species, the penetration and retention behind the scar-face in slash pine was generally satisfactory when the poles were air seasoned, steam conditioned, and treated to a 10-pound retention, while it was erratic behind the scar-face in longleaf pine. Since the two species are indistinguishable after the tree is cut and peeled, it was necessary to devise a means of pretreating scar-faces so that penetration and retention would be satisfactory regardless of species. This paper describes a study to find commercially acceptable methods of pretreating longleaf pine poles.

METHODS TO INCREASE PENETRATION

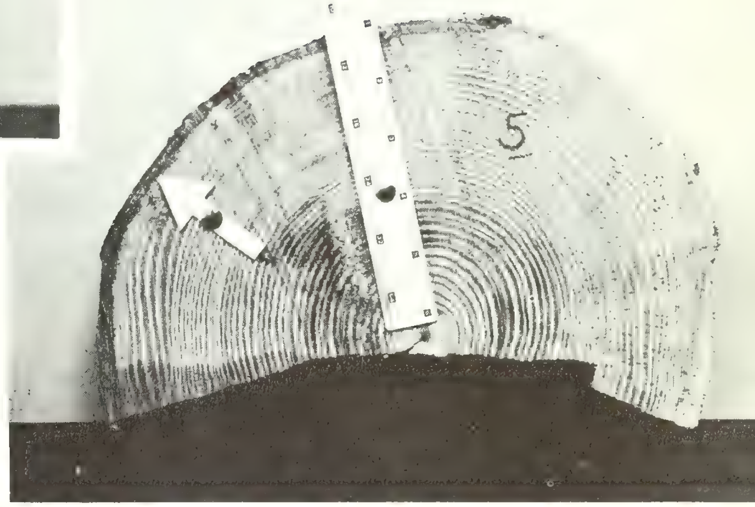
Preliminary trials were made on short bolts rather than full-length poles. Four methods were tested including incising, since Snow had experienced some success with penetration behind the few scar-faces he incised. Scar-faces for testing were cut from longleaf pine trees on the Olustee Experimental Forest near Lake City, Florida (fig. 1). Pitch-soak on these faces varied in depth and pattern (fig. 2).

Bolts containing the scar-faces were about 50 inches long and were divided into 4 groups of 5 each (fig. 3). Group A bolts were incised (fig. 4). Group B bolts were bored (fig. 5). Group C bolts were soaked in sodium hydroxide (fig. 6), and Group D bolts were soaked in gum turpentine. In each group there were matched control sections taken from alternate ends of the bolts, which were crosscut in half prior to treating.

After pretreating by these four methods, the bolts were end-coated with two coats of a resorcinol-phenol-formaldehyde resin to prevent end-penetration of creosote. The test and control bolts were then pressure treated with creosote at The Langdale Company in a charge of full-length poles. The charge was steam conditioned for 13 hours at 259° F. and treated for 3 hours.

2/ Page, Rufus H. Preservatives and turpentined utility poles. Forest Farmer 20(6): 11-12, 14. 1961.

Figure 1. --Sample trees used in evaluating methods of pretreating ranged from 9 to 16 inches d. b. h. and had been worked 4 seasons, 1957 through 1960, using a bark hack cutting a 3/4-inch streak. The streaks had been treated with a 50-percent solution of sulphuric acid.



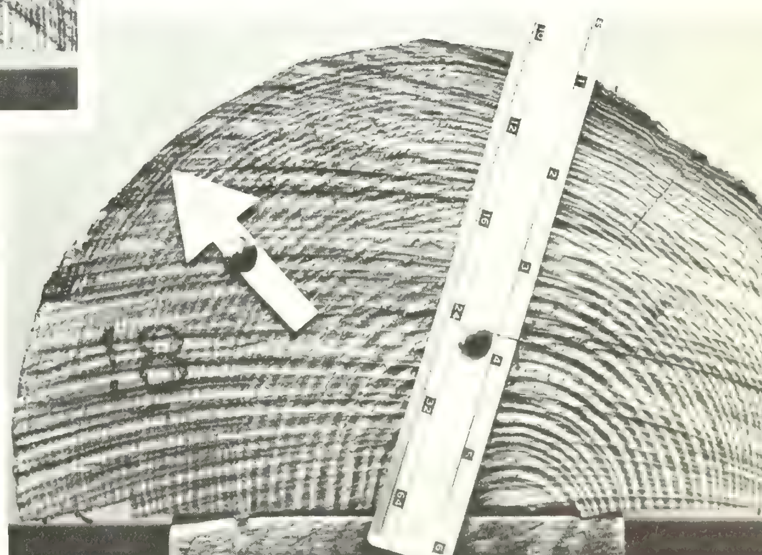


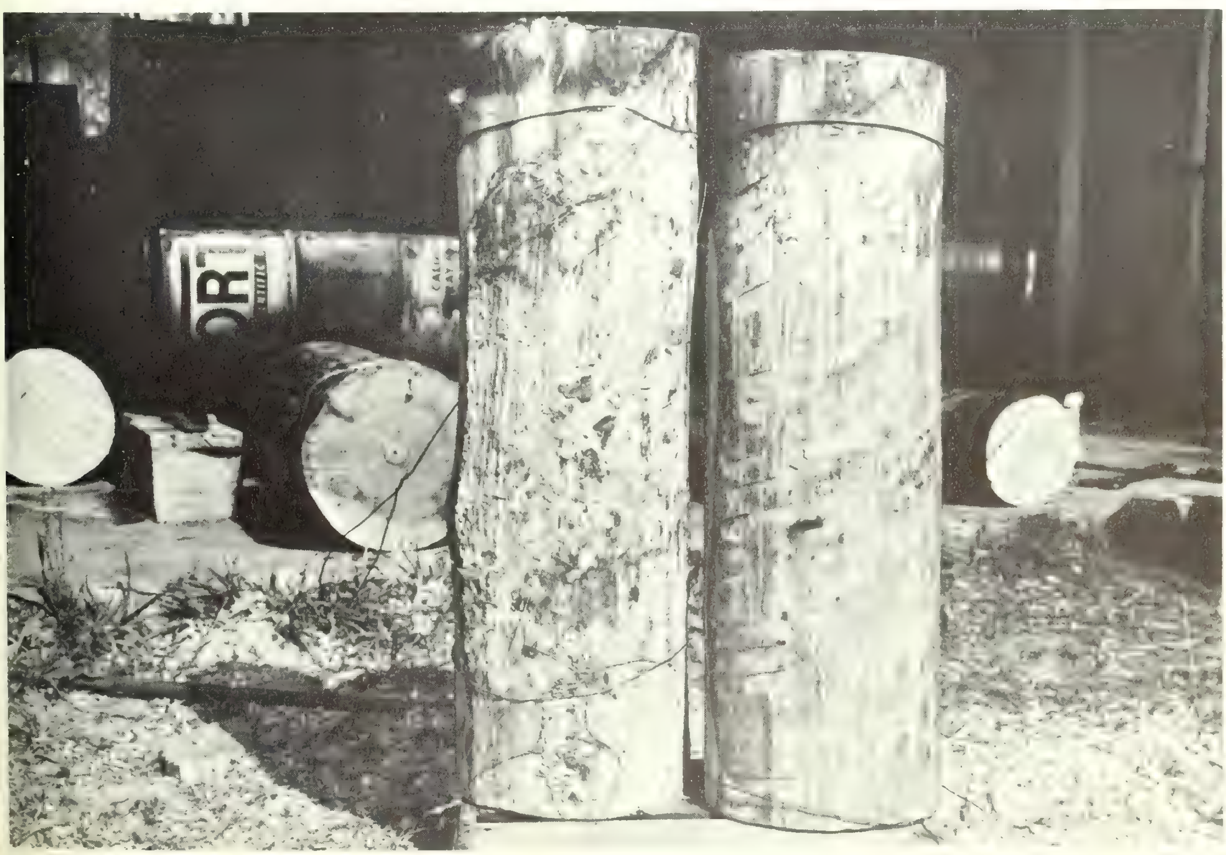
Figure 2. --Cross sections of scar-faces cut to show the pitch pattern in the vicinity of the worked-out face. Heavy pitch deposits ranged from 1/8 inch to 3/8 inch in depth, and appeared to average about 1/4 inch.

Figure 3. --The moisture content of these bolts, which were air-dried, ranged from 20.0 to 38.6 percent and averaged 28.1 percent when pretreated. The ends of the bolts were coated with an aluminum-asphalt roof coating compound containing asbestos fibers, and then wrapped in a polyethylene film to prevent excessive end checking.

Figure 4. --This homemade hand incisor had a "chisel-point" tooth 1/8 inch wide, 1/2 inch long, and 3/4 inch deep. The test bolts were incised on 1-inch centers. Hand incising is slow and laborious. It is reported that a machine method of incising only the scarface has been devised for commercial operations.

Figure 5.--Holes were bored on 1-inch centers to a depth of 3/4 inch with a 1/8-inch drill. Even though boring proved the best of four methods tested, it would probably be more costly to bore than to incise scar-faces of full length poles on a production basis.

Figure 6. --A heavy deposit of gum similar to that appearing on the test bolt at left was almost completely removed by soaking either in hot caustic or hot turpentine. The bolt on the right was treated with a 3-percent solution of sodium hydroxide at 175° F. for 4 hours. Group D bolts were kept in hot gum turpentine (165° F.) for 6 hours.



Results

Actual net retention by gauge for the charge was 8.9 pounds per cubic foot. The bolts were allowed to cool for several hours before the test cores were removed. Seven randomly selected cores were taken from the face and seven from the back of each bolt, and the sapwood thickness and depth of preservative penetration measured for each. The cores were then assayed (fig. 7).

All four methods proved satisfactory, although boring was most effective (table 1). Actually, penetration of creosote was 100 percent for both bored and incised bolts, but retention for bored bolts was 3.5 pounds more per cubic foot than for incised. However, since retention of the incised bolts (10.3 pounds) was considerably more than is required by a leading pole buyer (6.7 pounds by assay for an 8.9 pound gauge retention), it was decided to incise full-length poles for further testing and for statistical analysis because this method was satisfactory and appeared less costly to apply commercially than boring or soaking.

Figure 7. --Retention analysis of the cores from the test bolts was made at The Langdale Company's analytical laboratory. Toluene was used for extraction. The cores were placed in the extraction apparatus, heat was applied and the toluene was refluxed at a rate of 1 drop per second for 1 hour 45 minutes. Cores were then removed from the apparatus and placed in an oven to dry for 1 hour at 125° C. They were then removed to a desiccator for 15 minutes. Four drops of Nekl NS (sulfonated aliphatic polyester) were used to remove the water from the condensing tube. Five Interjoint Reflux condensers were used in the distillation process.

Table 1. --Relative effectiveness of four pretreating methods

Method of pretreating	Pretreated bolts				Control bolts			
	Penetration 1/ 2/		Retention 3/ 4/		Penetration 1/ 2/		Retention 3/ 4/	
	Face	Back	Face	Back	Face	Back	Face	Back
	- - Percent - -		Pounds per cubic foot		- - Percent - -		Pounds per cubic foot	
Boring	100.0	100.0	13.8	9.5	100.0	100.0	12.9	11.9
Incising	100.0	100.0	10.3	9.7	92.8	100.0	10.2	8.8
Caustic	93.6	100.0	10.2	8.8	99.2	100.0	8.5	9.2
Turpentine	99.6	100.0	10.1	7.3	99.7	100.0	9.8	7.0

1/ Percent penetration of sapwood, average of 35 cores each method of pretreating.

2/ A. W. P. A. C4-60 (Southern pine) - for 10-pound treatment, minimum penetration, 3.0 inches or 90 percent of sapwood.

3/ By assay, average of 35 cores each method of pretreating.

4/ Retention by gauge for the charge containing the test bolts was 8.9 pounds per cubic foot. One leading pole buyer requires that retention by extraction be at least 75 percent of retention by gauge. Based on this figure, a satisfactory retention by assay for 8.9 pounds by gauge would be 6.7 pounds per cubic foot.

PROCESSING FULL-LENGTH POLES

The next step was to incise full-length poles and test penetration and retention for different seasoning periods. Of the 84 longleaf pine trees selected and marked for identification on 2 tracts near Valdosta, 63 had been turpentined and 21 had not. Twenty-one of the poles with scar-faces were cut 39 days after the other test poles. These 84 poles were divided into 4 lots of 21 poles each. They were processed in the usual manner (fig. 8). Lot I consisted of 21 scar-faced poles seasoned 68 days and incised. Lot II was made up of 21 scar-faced poles seasoned 68 days and not incised. These served as controls. Lot III contained 21 scar-faced poles seasoned 29 days and incised, and Lot IV, 21 unworked or round poles seasoned 68 days and not incised, for use in determining the relationship between midpoint and face borings. Incising was done with a hand incisor (fig. 9).

The charge in which the test poles were treated contained 1,567 cubic feet of wood. It was steamed for 13 hours at 245° F. and treated for 3 hours. Net retention by gauge at 100° F. was 11.54 pounds per cubic foot. Poles were permitted to cool for 9 hours before the cores were taken (fig. 10).

The depth of sapwood and depth of penetration of creosote were measured as soon as each core was taken from the pole. A dye was used to distinguish heartwood from sapwood where these were not clearly defined. A core was taken from the midpoint of each pole and the depth of penetration measured, after which the outer $\frac{1}{2}$ inch of all cores, except midpoint cores, was discarded and the next $1\frac{1}{2}$ inches cut from the core and retained. The outer $\frac{1}{2}$ inch, which is the richest part of the core, was discarded before

extraction analysis in order to minimize the effect of pitch on the amount of oil extracted. Analysis of the part of the core from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches from the surface is now included in American Wood-Preservers' Association specifications.

Figure 8. --Sample poles were peeled, rossed, and stacked to dry on The Langdale Company's pole seasoning yard. The average moisture content for Lot I poles just before treating was 20.1 percent, for Lot II poles 19.6 percent, for Lot III poles 30.7 percent, and for Lot IV poles 21.0 percent. Moisture content determinations were made with a resistance-type moisture meter on the fresh cut ends of the poles just after they were trimmed. Four determinations were made for each pole, two at the butt and two at the top, one from the heartwood area and one from the sapwood area. In a previous study, moisture content measurements made with a resistance-type meter were compared with those from the same poles made by oven drying a pie-shaped disc, and for most readings below 30 percent the difference did not exceed 3 percent.

Figure 9. --The scar-faces of all poles in Lot I and Lot III were incised. Incisions were made in parallel rows approximately 1 inch apart and running the length of the face. The vertical distance between incisions was about 1/2 inch. Depth of incision was 3/4 inch, the length of the chisel-point tooth.

Figure 10. --Taking cores from treated poles to sample retention and penetration of preservative. Seven randomly selected test cores were taken from the turpentine-face location of all Lot I, II, III, and IV poles. An oilcloth with numbered circular holes was used to mark the location of the test cores.

Results

There was so little variation in penetration of the test cores from the full-length poles that no statistical analysis of these data was made. However, from an analysis of retention data for Lot I poles (incised after seasoning 68 days) we would expect to obtain satisfactory retention of creosote more than 90 percent of the time. Lot III poles (incised after seasoning 29 days) showed up better in this respect, and it is estimated that the wood behind the scar-faces of these poles would meet minimum retention standards more than 99.95 percent of the time. Since the average penetration into the sapwood (table 2) for Lot III poles was also better than for Lot I poles, it is apparent that in this study poles seasoned for only 29 days and incised treated better than poles seasoned for 68 days and incised.

Lot IV poles, which consisted of poles from unworked timber, were bored where the scars would have been located if the poles had been cut from turpentined trees, and also at midpoint. Sapwood of all cores was entirely penetrated, indicating that borings obtained from the face area and from the midpoint of the poles were comparable for the purpose of analyzing preservative penetration.

Table 2. --Penetration and retention of cores from full-length test poles, by groups

Lot number	Description	Average [1] penetration of sapwood	Individual cores meeting A. W. P. A. requirements for penetration [2]	Average retention	Individual poles meeting A. W. P. A. requirements for retention [3]
		Percent	Percent	Pounds per cubic foot	Percent
I	Turpentined, seasoned 68 days, incised	97	95	14.42	100
II	Turpentined, seasoned 68 days, not incised	93	84	13.45	86
III	Turpentined, seasoned 29 days, incised	99	97	15.97	100
IV	Round, seasoned 68 days, not incised	100	100	13.23	95

1/ Calculated by adding percent penetration of each group of cores and dividing by number of groups.

2/ Calculated by adding number of cores meeting A. W. P. A. requirements and dividing by total number of cores involved.

3/ 7.5 pounds per cubic foot by extraction.

CONCLUSION

The results of this study show that bark-hacked, acid-treated, turpentined faces of longleaf pine should meet minimum standards of penetration and retention almost 100 percent of the time if the poles are seasoned to an average moisture content of about 30 percent and then incised and steam conditioned before treating. Incising should work equally as well for slash pine poles, since previous studies indicate that in most cases the scar-face of this species treats well without incising. It must, therefore, be concluded that wood behind both longleaf and slash pine turpentine scars will treat well enough for the poles to meet minimum specifications of both the American Wood-Preservers' Association and the American Standards Association if the poles are air seasoned, incised, and steamed.

It will be necessary for treating plants that buy worked-out turpentined poles to weigh the cost of incising against the added value of additional pole length when the tree is not jump-butted.

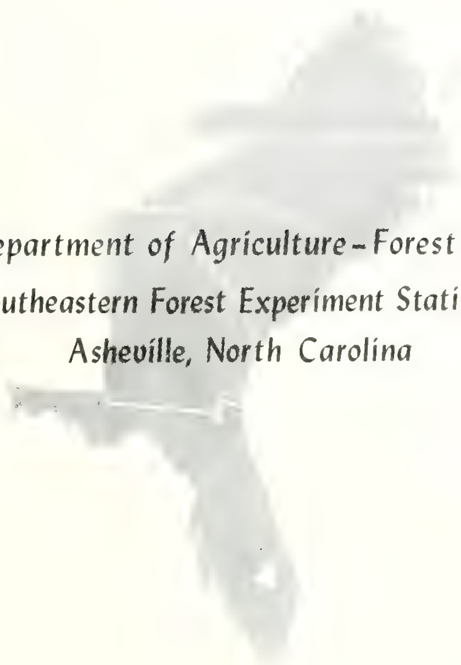
Agriculture Asheville

tation Paper No. 153 November 1962

Recreation impact on Southern Appalachian campgrounds and picnic sites

by

Thomas H. Ripley



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Where to locate and how to plan, rehabilitate, and manage developed camping and picnicking sites are problems of considerable and growing import. Controversy involving aesthetics, beauty (both natural and planned), and "user satisfaction" notwithstanding, it may be assumed that preservation of the natural forest environment at some recognizable level is a desirable objective. The capacity of man to adjust to change in natural or artificial plant communities does not preclude an objective to manage the natural forest environs in a pleasing and recognizable manner--to maintain a tree cover. It perhaps is not essential to have tree growth actually within a developed site, but it may be argued that some form of tree growth and nearly complete ground cover in such sites is desirable, if for no other reason than for protection.

Dana (1957) in his problem analysis of research in forest recreation identified major fields of priority work. Among the 17 he listed, three deal directly with relations between biological and physical properties of sites, design, and use loads. Significant contributions in this field of work have been extremely limited, and work in the Southern Appalachians apparently has never been undertaken.

Wagar[1/] made a major contribution by developing predicting equations of the durability of biotic communities. His data collections and analyses from southeastern Michigan gave two prediction equations. One involved three independent variables predicting reduction in weight of vegetation. The other equation involved four independent variables and predicted the weight of vegetation clipped from treated plots. R^2 values were 0.64 and 0.95 for the two solutions, respectively. Wagar (1961) published this information and used the variables in the first solution to develop a "trampling" slide rule. Three independent variables, X_1--the percent of grass and woody vines present in low-growing vegetation before trampling; X_2--the percentage of direct sunlight blocked by shade-casting objects; and X_3--ovendry weight in

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1/ Wagar, J. A. The carrying capacity of wild lands for recreation. University of Michigan. 1961. [Unpublished Ph. D. dissertation.]

grams of low-growing vegetation, were used where Y was the weight of low-growing vegetation that survived trampling. This equation is analogous to the one Wagar reported in his dissertation, op. cit., accounting for 65 percent of the variation in treatment effects. Wagar's work served importantly in developing concepts, and showed quite clearly that this approach to an understanding of relations between vegetal characteristics and site degradation was feasible.

THE STUDY

This study was conducted, first, to identify and describe general relations between the physical and biological properties of developed sites, use loads, and degrees of site degradation; and secondly, to use these findings to aid in site selection, development, and rehabilitation.

Forty-two developed camping and picnic sites on the Cherokee, Nantahala, and Pisgah National Forests were used in this study. Areas selected were ten or more years old and contained from one to twenty-one family units (a picnic table and accessory facilities) per site. Field sampling for this work was accomplished during the summer of 1961. Data collected by the National Forests for the Outdoor Recreation Resources Review Commission on each developed site also served as an important source of information in addition to field data collections.

It was thought that the use impacts on camping areas versus picnic areas could differ considerably--with camping probably producing a much more pronounced effect. It was also suspected that soil origin might have a controlling effect on all of the measured variables. Accordingly, sites were stratified on the basis of soil origin as either transported or residual and principal use (camping and picnicking).

Samples to give information for this study of site-use relations were taken in 280 family units (in the 42 campgrounds and picnic areas selected) with picnic tables serving as centers for plots with $\frac{1}{2}$-chain radii. Definitions of all variables used in regression analysis and units of measurement are given in the following tabulation:

X_1--Outside depth of A horizon as tabulated in inches and tenths.

? X_2--Hydrologic condition as recorded in relative numerical values in units or tenths based on the alignment chart (fig. 1).

X_3 and X_4--Soil textures for A and B horizons, respectively, were recorded in units, tenths, and hundredths of millimeters in particle size diameters.

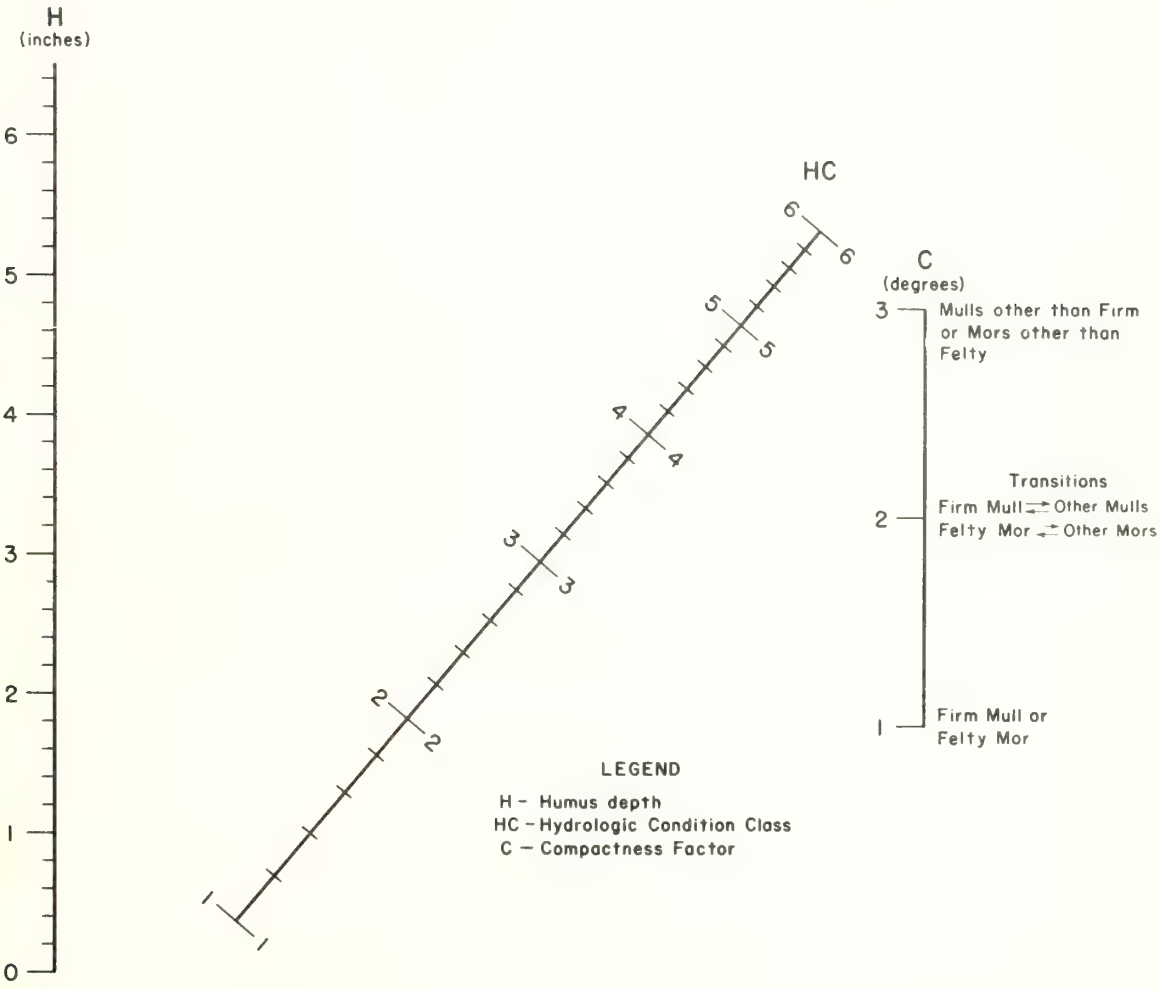

Figure 1. --Chart for determining present hydrologic condition of forest and woodland.

X_5--Aspect was transformed using a sine curve based on findings by Doolittle (1957). Associated values for aspect are:

N = 1.7	S = 0.3
NE = 2.0	SW = 0.0
E = 1.7	W = 0.3
SE = 1.0	NW = 1.0

FLAT = 1.0

X_6--Position on slope was coded using values of 0 through 1.00, corresponding to five positions--ridge, upper third, middle third, lower third, and bottom--with ascending values corresponding to general increases in site potential:

Bottom	1.00	Upper 1/3	0.25
Lower 1/3	0.75	Ridge	0.00
Middle 1/3	0.50		

X_7--Percent slope was recorded as a whole number as measured directly with an Abney hand level.

X_8--Basal area was recorded in units and tenths of square feet for each sample plot with 1-chain diameter.

X_9--Percent conifers in stand was used as the whole percentage based on the ratio of conifer to total stems.

X_{10} and X_{11}--Percent high and total canopy, respectively, were taken directly from field observations.

X_{12}--Percent shrub barrier was computed by dividing the area protected from human use by shrub cover by total area of the plot.

X_{13}--Acres per table, recorded in units and tenths, was computed using tables sampled and total acreage in the general boundary of the developed site (wherever acreage figures were not available from NFORRR[2/] observations, acreage was determined by running the boundary with a hand compass and pacing).

X_{14} and X_{15}--Distance to nearest table and distance to nearest parking were recorded in units and tenths of chains.

2/ National Forest Outdoor Recreation Resources Review.

X_{16}--Volume use per table was taken as the total number of visits estimated for the site divided by the number of tables sampled.

X_{17}--Months of use was recorded directly as a whole number taken from NFORRR data.

X_{18}--Percent slope "squared" was used as a whole number.

In addition, definitions, methods of computing, and units for analysis for the eight dependent variables are as follows:

Y_1--Percent change in depth of A horizon was computed by dividing the difference of the depth of A horizon between inside and comparable outside plot readings by outside plot readings.

Y_2--Percent change in hydrologic condition was similarly computed by dividing differences in hydrologic condition values by outside-the-plot readings.

Y_3 and Y_4--Bare ground was recorded as total percentage of bare ground, both unplanned and total, respectively.

Y_5--Percent of trees injured in each sample plot.

Y_6, Y_7, and Y_8--Degrees of erosion, root exposure, and vandalism, respectively, were taken from unit samples and were transformed for analysis as either -1 or +1, where -1 corresponds to subjective classes 1 and 2 of none or moderate, and +1 corresponds to subjective class 3, heavy.

Multiple regression solutions were generated for each Y variable for: (1) picnic sites on residual soils; (2) camping and picnicking sites on residual soils; (3) camping sites on transported soils; (4) picnicking sites on transported soils; (5) camping and picnicking sites on transported soils; and (6) all sites and all soils. All solutions for areas on residual soils used the full array of independent variables and 8 dependent variables. Analysis performed on transported soils and the summary for all sites and soils were based on 14 independent variables (X_5 through X_{18}) and 6 dependent variables (Y_3 through Y_8).

RESULTS

The results of the multiple regression analysis are shown in tables 1, 2, 3, 4, 5, and 6. Individual tables report separate values for picnicking use from camping use and residual soils from transported soils. Tables 2 and 3 give solutions for both types of recreation sites on residual and transported soils, respectively. Table 6 reports the findings for all sites on all soils. Two values are given in each cell for each significant X and Y variable combination: First is the F value, and second, the regression coefficient (b value) in the original units. An independent variable was considered significant when the F value obtained by adding it to the regression equation was greater than 3.000. Shown also in individual tables are the multiple correlation coefficients (R) and the percentage of variation in the solution explained by the variables shown (R^2 x 100). The b values represent the units of change in a Y variable associated with one unit of change in a significant X variable (except in the case of X_{16}, where volume of use is expressed per 1,000 visits). The sign of the b value indicates the direction of the slope of the regression line.

Table 1. --Regression solution for 93 picnicking sites on residual soils. Combinations [illegible] Y variables showing F values [illegible]

Independent variables		[illegible]	[illegible]	Y_3 Bare ground - [illegible]	Y_4 Bare ground - [illegible]	[illegible] Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of [illegible]	F			10.49	15.56				
	b			-11.56	-12.60				
X_2 Hydrologic condition	F		56.10	7.33	13.12	13.16			
	b		12.[illegible]	15.91	18.59	22.57			
X_3 Texture of [illegible]	F			19.25	3.58	3.92	[illegible]		
	b			131.76	61.71	88.17	3.67		
X_4 Texture of B horizon	F	15.23	24.36		3.79				
	b	-41.88	-33.17		32.70				
X_5 Aspect	F	30.87							[illegible]
	b	24.68							-.49
X_6 Position on slope	F					18.78	20.66	29.83	
	b					93.10	1.51	1.10	
X_7 Slope	F						3.10		
	b						.06		
X_8 Basal area of plot	F								
	b								
X_9 Conifer component	F					3.45	5.80		
	b					-.28	-.01		
X_{10} [illegible]	F		18.[illegible]	4.07	3.53		9.80	21.00	
	b		.30	.34	.26		.01	.01	
X_{11} Total canopy	F			5.06	8.36				
	b			.34	.36				
X_{12} Shrub barrier	F								
	b								
X_{13} Table density	F	10.08						16.16	4.63
	b	-2.56						-.11	-.09
X_{14} Table sp[illegible]	F					7.02			
	b					24.26			
X_{15} Proximity to parking	F	4.55					4.63		
	b	1.73					.09		
$X_{16/1000}$ Volume of use	F			8.21	11.03	4.92	11.02	3.66	
	b			1.30	1.30	2.20	.05	.02	
X_{17} Months of use	F								
	b								
X_{18} [illegible]	F								
	b								
Multiple regression [illegible] R		.6324	.7165	.6758	.7066	.5237	.6811	.7038	.3349
R^2 x 100		39.99	[illegible]1.34	45.67	49.93	27.43	46.39	49.53	11.22

Table 2. --Regression solution for 106 camping and picnicking sites on residual soils. Combinations of X variables yielding best solution for individual Y variables showing F values (best fit) and b values (sign and slope)

Independent variables		Y_1 Change in depth of A horizon	Y_2 Change in hydrologic condition	Y_3 Bare ground-unplanned	Y_4 Bare ground-total	Y_5 Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of A horizon	F			4.24					
	b			-3.27					
X_2 Hydrologic condition	F		68.25			8.69	9.17		
	b		14.95			16.85	-.31		
X_3 Texture of A horizon	F						11.03	3.34	
	b						2.18	1.01	
X_4 Texture of B horizon	F	11.61	35.84					7.43	
	b	-34.75	-56.30					-.88	
X_5 Aspect	F	31.24	21.98	12.69	8.29				7.54
	b	22.10	16.86	15.46	9.94				-.41
X_6 Position on slope	F	5.29	12.99		5.00	12.40		15.76	
	b	11.32	18.80		14.90	60.50		.74	
X_7 Slope	F						4.51		
	b						.07		
X_8 Basal area of plot	F					4.44			
	b					1.90			
X_9 Conifer component	F					4.76			
	b					-.32			
X_{10} High canopy	F						7.23	25.33	
	b						.01	.01	
X_{11} Total canopy	F			25.82	27.54				
	b			.48	.43				
X_{12} Shrub barrier	F								
	b								
X_{13} Table density	F	11.68					3.71	13.95	4.46
	b	-2.78					-.09	-.11	-.09
X_{14} Table spacing	F					7.43			
	b					23.48			
X_{15} Proximity to parking	F	3.81							
	b	1.50							
$X_{16/1000}$ Volume of use	F			7.61	7.11	3.92	5.43		
	b			.46	.38	.95	.04		
X_{17} Months of use	F								
	b								
X_{18} $(\text{Slope})^2$	F								
	b								
Multiple regression coefficient R		.6324	.7239	.6038	.6348	.4916	.5797	.6713	.2861
R^2 x 100		39.99	52.40	36.46	40.30	24.17	33.61	45.06	8.19

It is inevitable, indeed expected, that in regression analyses with a large number of independent variables that some significant F values (in this case somewhere between 5 and 10 percent) would occur by chance alone. This may be the case in a number of F values given in tables 1 through 6 and may explain several otherwise inexplicable irregularities. By and large, however, the multiple correlation coefficients are high--much higher in fact than expected. In most instances, it is obvious that the solutions are consistent and explainable. There appears to be a very low risk of inaccurate conclusions based on random error.

Table 3.--Regression solution for 53 camping sites on transported soils. Combinations of X variables yielding best solution for individual Y variables showing F values (best fit) and b values (sign and slope)

Independent variables		Y_1 Change in depth of A horizon	Y_2 Change in hydrologic condition	Y_3 Bare ground-unplanned	Y_4 Bare ground-total	Y_5 Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of A horizon	F								
	b								
X_2 Hydrologic condition	F								
	b								
X_3 Texture of A horizon	F								
	b								
X_4 Texture of B horizon	F								
	b								
X_5 Aspect	F						10.14		
	b						-2.19		
X_6 Position on slope	F			11.54	10.18			15.81	
	b			-17.26	-16.40			-1.28	
X_7 Slope	F								
	b								
X_8 Basal area of plot	F								
	b								
X_9 Conifer component	F								
	b								
X_{10} High canopy	F								
	b								
X_{11} Total canopy	F								
	b								
X_{12} Shrub barrier	F						3.10		
	b						-.05		
X_{13} Table density	F			101.42	86.74		13.05		
	b			-41.83	-39.12		-.98		
X_{14} Table spacing	F						7.72	7.63	
	b						.90	.65	
X_{15} Proximity to parking	F								
	b								
$X_{16}/1000$ Volume of use	F					7.60			
	b					13.60			
X_{17} Months of use	F								
	b								
X_{18} $(\text{Slope})^2$	F								
	b								
Multiple regression coefficient R				.8529	.8345	.3601	.6392	.5296	
$R^2 \times 100$				72.74	69.64	12.97	40.86	28.05	

Table 4. --Regression solution for 121 picnicking sites on transported soils. Combinations of X variables yielding best solution for individual Y variables showing F values (best fit) and b values (sign and slope)

Independent variables		Y_1 Change in depth of A horizon	Y_2 Change in hydrologic condition	Y_3 Bare ground-unplanned	Y_4 Bare ground-total	Y_5 Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of A horizon	F								
	b								
X_2 Hydrologic condition	F								
	b								
X_3 Texture of A horizon	F								
	b								
X_4 Texture of B horizon	F								
	b								
X_5 Aspect	F					5.92	9.48	5.14	
	b					10.94	-.46	-.26	
X_6 Position on slope	F			18.53	23.92	10.95			
	b			-72.33	-72.83	70.97			
X_7 Slope	F								
	b								
X_8 Basal area of plot	F						4.86	9.63	
	b						-.04	-.05	
X_9 Conifer component	F								
	b								
X_{10} High canopy	F			15.25	18.49				4.60
	b			.65	.64				.0
X_{11} Total canopy	F			8.00	10.66				12.68
	b			-.40	-.41				-.02
X_{12} Shrub barrier	F			8.44	8.66	7.34			
	b			.50	.45	-.48			
X_{13} Table density	F			13.87	3.74			5.21	
	b			-8.36	-3.85			-.17	
X_{14} Table spacing	F					3.50			3.46
	b					-4.97			.18
X_{15} Proximity to parking	F								
	b								
$X_{16/1000}$ Volume of use	F			3 70	3.55				
	b			.60	.52				
X_{17} Months of use	F						14.24		7.70
	b						-.33		- 24
X_{18} $(\text{Scope})^2$	F								
	b								
Multiple regression coefficient R				.5995	.5897	4774	.4230	.3761	.4281
R^2 x 100				35.94	34.77	22.79	17.89	14.15	18.33

Table 5. --Regression solution for 174 camping and picnicking sites on transported soils. Combinations of X variables yielding best solution for individual Y variables showing F values (best fit) and b values (sign and slope)

Independent variables		Y_1 Change in depth of A horizon	Y_2 Change in hydro-logic condition	Y_3 Bare ground-unplanned	Y_4 Bare ground-total	Y_5 Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of A horizon	F								
	b								
X_2 Hydrologic condition	F								
	b								
X_3 Texture of A horizon	F								
	b								
X_4 Texture of B horizon	F								
	b								
X_5 Aspect	F						17.11		
	b						-.46		
X_6 Position on slope	F			28.23	29.21		6.25	7.79	
	b			-38.58	-36.27		-.88	-.72	
X_7 Slope	F								
	b								
X_8 Basal area of plot	F						3.28	10.45	
	b						.03	.05	
X_9 Conifer component	F			5.65	5.99				
	b			.14	.13				
X_{10} High canopy	F			8.83	9.72				4.03
	b			.42	.40				.01
X_{11} Total canopy	F			4.18	4.66				9.81
	b			-.25	-.24				-.02
X_{12} Shrub barrier	F			6.73	6.42	5.95			
	b			.42	.38	-.42			
X_{13} Table density	F			26.74	12.04		7.33	4.78	
	b			-10.90	-6.76		-.25	-.16	
X_{14} Table spacing	F					9.74			4.47
	b					-7.31			-.19
X_{15} Proximity to parking	F					6.14			
	b					-1.76			
$X_{16/1000}$ Volume of use	F						3.77		
	b						.03		
X_{17} Months of use	F					3.40	9.22		10.39
	b					3.24	-.23		-.22
X_{18} $(\text{Slope})^2$	F								
	b								
Multiple regression coefficient R				.5749	.5359	.3785	.4265	.3472	.3649
$R^2 \times 100$				33.05	28.72	14.33	18.19	12.05	13.32

Table 6. --Regression solution for 280 camping and picnicking sites on all soils. Combinations of X variables yielding best solution for individual Y variables showing F values (best fit) and b values (sign and slope)

Independent variables		Y_1 Change in depth of A horizon	Y_2 Change in hydrologic condition	Y_3 Bare ground-unplanned	Y_4 Bare ground-total	Y_5 Trees injured	Y_6 Degree of erosion	Y_7 Degree of root exposure	Y_8 Degree of vandalism
X_1 Depth of A horizon	F								
	b								
X_2 Hydrologic condition	F								
	b								
X_3 Texture of A horizon	F								
	b								
X_4 Texture of B horizon	F								
	b								
X_5 Aspect	F						5.81		
	b						-.23		
X_6 Position on slope	F			8.18	4.34				
	b			-16.63	-10.63				
X_7 Slope	F								
	b								
X_8 Basal area of plot	F								3.08
	b								.02
X_9 Conifer component	F			9.77	9.36	9.30		5.48	5.51
	b			.14	.12	-.19		.003	-.004
X_{10} High canopy	F			29. 56	32.94		8.33	16.08	
	b			.38	.35		.01	.01	
X_{11} Total canopy	F						4.00		5.82
	b						-.01		-.01
X_{12} Shrub barrier	F								
	b								
X_{13} Table density	F			4.76		10.80	9.48	8.63	
	b			-2.34		-4.82	-.13	-.09	
X_{14} Table spacing	F								
	b								
X_{15} Proximity to parking	F					9.83			
	b					-2.75			
$X_{16/1000}$ Volume of use	F			6.70	5.26		7.32		
	b			.73	.57		.03		
X_{17} Months of use	F								8.43
	b								-.17
X_{18} (Slope)^2	F								4.29
	b								.003
Multiple regression coefficient R				.4265	.4016	.3091	.3019	.3379	.2834
R^2 x 100				18.19	16.13	9.55	9.11	11.42	8.03

DISCUSSION

In the analysis on residual soils the relation between outside hydrologic condition (representing the comparable undisturbed site) and percent change in hydrologic condition is significant. It was evident both on picnic areas and all areas together (too few camping areas were taken for meaningful separate analyses) that increased recreation use is directly related to reductions in hydrologic condition, and that change in this respect is greatest among soils having a high natural capacity for water intake and storage.

Texture of the B horizon was associated with change in depth of A horizon and hydrologic condition. In both cases, increased particle size was significantly related to a decrease in change when subjected to recreation use. It might be conjectured that better internal drainage in the B horizon reduced erosion.

Depth of the A horizon, as might be expected, was also significantly related to table density- as expressed in tables per acre. As table density increased, depth of the A horizon became reduced. Distance to parking, which also showed a direct relation to change in A horizon, is unexplainable, and the low F value may have resulted from chance error or because more distant units are higher up on thinner soils.

On all residual soils, aspect and, less strikingly, position on slope were related to reduction in depth of A horizon and lowering hydrologic condition. On the more fertile sites the impact of recreation use appears to be more important because there was inherently more measurable damage that could be done.

In the results shown in table 2 for all residual soils, variable X_5 (aspect) in association with Y_3 and Y_4 (bare ground dependents) and X_6 (position on slope) and Y_4 and Y_7 (root exposure) disagree generally with the expected negative relations seen between X_5 and Y_6, and X_6 and Y_3, Y_4, Y_6, and Y_7 on transported soils (table 5). Although it is recognized that some increases in bare ground would be associated (normally) with higher position on slope (as seen in table 5), it was thought that this would be small in comparison to the effects of human use. It should be pointed out that the significant relations between X_5 and Y_3 and Y_4, and X_6 and Y_4 result in part from limited and probably nonrepresentative 13-unit sample of camping on residual soils. For this reason, these data were not tabulated but were totaled with the picnicking data in table 2. Perhaps more importantly, the conflicts seen here may result from a much heavier use at lower positions on slope because of unit location. Field observations tend to substantiate weaker results for transported soils and suggest that position on slope and very likely aspect may be important, and that with decreased fertility on thinner, drier, and higher soils there may be increased damage.

The fairly consistent high relation between damage to trees, Y_5, and position on slope, X_6, may, in part, result from less use on upslope units by location than lower units which are usually closer to roads. This may also result from a probable relation between position on slope and species composition, with the species occurring at higher positions on slope somewhat less vulnerable to damage.

Other related variables common on all soils offer important relationships. For all areas tested the most important relations were those associated with bare ground, erosion, and tree damage. Degrees of root exposure and vandalism apparently were only weakly related to principal X variables and, accordingly, warrant only passing mention in this discussion.

Quite likely the most important relationships seen in this analysis for all sites and soils were those between the amount of high canopy and bare ground, erosion, and root exposure. In all cases an expected and predictable detrimental change in amount of understory and damage to soil through erosion was associated with an increase in crown closure (high canopy).

The negative and perhaps unexpected relation between total canopy and bare ground value in picnic areas on transported soils and both areas on transported soils probably results from high canopy values associated with highly uneven, broken crowns. It appeared that there were fewer two-storied stands on residual soils than on transported soils and actually high and total canopy were essentially one. On transported soils the frequent presence of two-stand conditions was apparently reflected in total canopy and negative bare ground relations where breaks in stands actually improved conditions for development of ground cover. This effect of canopy breaks apparently drops out on all sites and soils and only high canopy remains important. Further, increase in the ratio of conifers to hardwoods is associated with reduction in ground cover and increased root exposure. Quite likely, this association is linked generally to the distribution of conifers on thinner soils.

Acres per table were consistently associated with damage, as might be expected; apparently table spacing was less important. It is conjectured that distance between tables was weak or contradicting, principally because spacing is generally held to specifications along roads and loops. Furthermore, it is suspected that what is seen here in the association between table density and damage is really the result of increased table density to accommodate increasing demand which in turn is associated with heavier use damage. Observations confirmed the thesis that virtually all damage is localized, and only where tables are very close together would spacing or density be a problem. This suggests that up to a point (perhaps aesthetically rather than biologically) table spacing may be of only minor importance in controlling site damage. This is further supported by the expected relation which was seen between volume of use and site degradation as expressed in decline of ground cover and site erosion with increase in volume of use.

Distance to the nearest parking facility was importantly, though not strongly, associated with site degradation for all areas. Although this did not result in significant relation to reduction in ground cover and erosion, tree damage was inversely related to distance and the latter was thought to be an important, controlling factor.

Shrub barrier, expressed as square footage of the plot protected from use by shrubs, was related to damage on picnicking sites. As the amount of shrub barrier increased, so did damage. It seems safe to conclude that this result was produced by a compression of use; it is also possible that this relationship resulted from an active program of shrub planting where heavier traffic was damaging the site. In contrast, an inverse relation between increased shrub barrier and reduction in tree injury was seen.

Some form of tree growth in developed sites is generally considered desirable.

Information on the effects of recreation use on developed sites was gathered from 280 family units in 42 campground and picnic sites in the Southern Appalachians.

Heavy use and damage to soil and vegetation were closely confined to a small area immediately surrounding the picnic table.

The amount of bare soil and associated damage in the immediate vicinity of a picnic table was related to the amount of use, but was also related directly to the amount of overstory canopy.

Failure to maintain nearly complete ground cover in developed sites results in soil loss and root exposure.

Reduced depth of the A horizon was most striking in highly fertile areas with poor drainage in the B horizon.

The presence of heavy shrub growth in the immediate vicinity of trees would have provided protection and prevented heavy injury seen in this exposed situation.

Although design and layout may have less control over vandalism than over other types of damage, vandalism may be reduced by modifications in site plans.

MANAGEMENT IMPLICATIONS

A number of relations seen in this study and analysis may have important management implications. As enumerated, they may suggest some management guides or revision in area treatment policy.

1. Although there are conflicts in the data, it appeared generally that more fertile sites were better able to withstand use and maintain vegetation.

2. Slope in the immediate vicinity of the picnic table or family unit appears to be less important than many other variables, and moderately steep slopes in local areas within a site may be acceptable.

3. Although no absolute values were obtained in this study, it was evident that dense tree canopies adversely and importantly limit growth of ground level species that protect the site. It might be inferred, then, that for most areas canopy reduction could produce important understory regrowth and decrease area soil losses.

4. The findings in this study suggest that, because individual unit use is closely confined to the picnic table, table spacing is a minor factor (aesthetics excepted). Further, the ratio of tables per acre, though significant, was probably of limited direct importance at reasonable densities. This suggests that closely spaced units used on a rotation basis, for example by shifting tables, might be useful in reducing site damage.

5. The amount (square footage) of ground effectively protected by shrub growth from human use was directly related to increases in site degradation. Apparently, shrub barrier is very effective in protecting local areas and reducing tree damage but must be used judiciously to prevent abnormal compression of use.

6. It appears that layout of parking facilities does control area use and that parking facilities can be distributed to effect uniform use that may result in lessened impact on local areas. Although distance between parking areas and family units was not significantly related to soil and vegetation losses, tree damage (as a measure of degradation) decreased as distance to parking increased.

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A Method for Determining the Slope of Neutron Moisture Meter Calibration Curves

by

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A Method for Determining the Slope of Neutron Moisture Meter Calibration Curves

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The neutron method of measuring soil moisture is coming into use more and more since reliable commercial equipment has become available and is rapidly replacing other methods of determining moisture content. In agricultural and hydrologic studies, moisture content is often measured over a period of time and the changes are related to evapotranspiration and drainage. Because of methods usually employed in gravimetric calibration, there is reason to doubt the accuracy of moisture changes thus determined.

Described simply, the neutron method consists of placing a source of fast neutrons in a soil mass, recording the number of impulses produced in a detector tube by returning slow neutrons, and relating the slow neutron count to the volume of moisture in the soil (1, 2, 5). For commercially available instruments, the relation between moisture and counts is

$$M = a + \frac{1}{b} X \tag{1}$$

where M is moisture content in percent by volume, a is a constant, b is the slope of the curve in counts per percent moisture, and X is the slow neutron count per unit time. Used to calculate moisture changes, the equation becomes

$$M_1 - M_2 = \frac{1}{b} (X_1 - X_2) \tag{2}$$

where $M_1 - M_2$ represents a change in moisture volume, b is the curve slope as previously defined, and X_1 and X_2 are counting rates at the same location at two points in time. Simplified further

$$m = \frac{1}{b} x \tag{3}$$

where m is the moisture change and x is the change in counts at the same location at two different times.

At first this relationship was thought to be independent of the soil material, but experience has shown that soils vary in their ability to moderate and absorb neutrons. Thus, the applicability of equation (3) is limited by the manner of deriving the b coefficient, i.e., the calibration method. Usually, the probe containing the radioactive source is calibrated by determining moisture volume gravimetrically after drying samples of the soil at 105° to 110° C.

However, soils retain varying amounts of water after drying, depending on mineral characteristics and texture (3, 4, 6). This tightly-held water also slows neutrons. If a probe is calibrated in soils of varying texture and mineralogy, as is often the case, it is possible to obtain different calibration curve slopes merely by changing the drying temperature.[1/] Furthermore, differences in neutron absorbers in the various soils used may increase or decrease the slope, thus adding or subtracting from the bias produced by failure to remove all water from gravimetric samples.

No fully satisfactory method has been reported for checking the gravimetrically derived b coefficients used to calculate soil moisture changes with time. A new calibration procedure is reported here which is believed to avoid much of the difficulty just discussed.

METHODS AND MATERIALS

The calibration method involves measuring both the volume of water required to displace air from a known volume of soil and the slow neutron count before and after addition of the water. Moisture volume and neutron counting rate changes are computed and used to obtain the calibration curve slope by solving for b in equation (3). Since the method does not involve volumetric sampling and drying of soil, differences in b coefficients between soils can be attributed directly to moderation and absorption characteristics of the soil rather than to variations in water content remaining after drying.

Slopes were determined for four Piedmont soils, Lloyd clay B horizon, Cataula clay B horizon, Cataula sandy loam C horizon, and Appling sand A horizon. Uniformity during the study was maintained by using the same equipment throughout. Slow neutron counting rates were obtained with a P-19 moisture probe and Model 2800 scaler. A 280-gallon steel drum 40 inches in diameter and 50 inches in height contained a vertical, centrally located, 1-5/8-inch seamless steel access tube (fig. 1). The drum was calibrated so that the volume of soil held by the drum could be determined to about 0.01 percent. A 55-gallon barrel was used to meter water into the drum.

Soil was passed through a $\frac{1}{2}$-inch mesh screen, mixed thoroughly, and packed to a uniform moisture and density. After the drum had been filled, a 3-minute count was taken with the probe resting on the bottom. Successive counts were made at 2-inch intervals as the probe was raised to the soil surface, providing a measure of moisture uniformity in the mid-portion of the drum. It was assumed that this measure was unaffected by soil-air interface effects.

Next, a measured volume of water was forced under low pressure into the base of the drum, saturating the soil with minimum entrapment of air in the soil column. Water addition was terminated when free water was visible at the soil surface. The volume of water required for saturation was measured to 0.01 percent, and, to obtain moisture change, volume of water added was divided by soil volume. This procedure was followed for each soil studied.

1/ Unpublished data. Coweeta Hydrologic Laboratory and Calhoun Experimental Forest, Southeastern Forest Experiment Station.

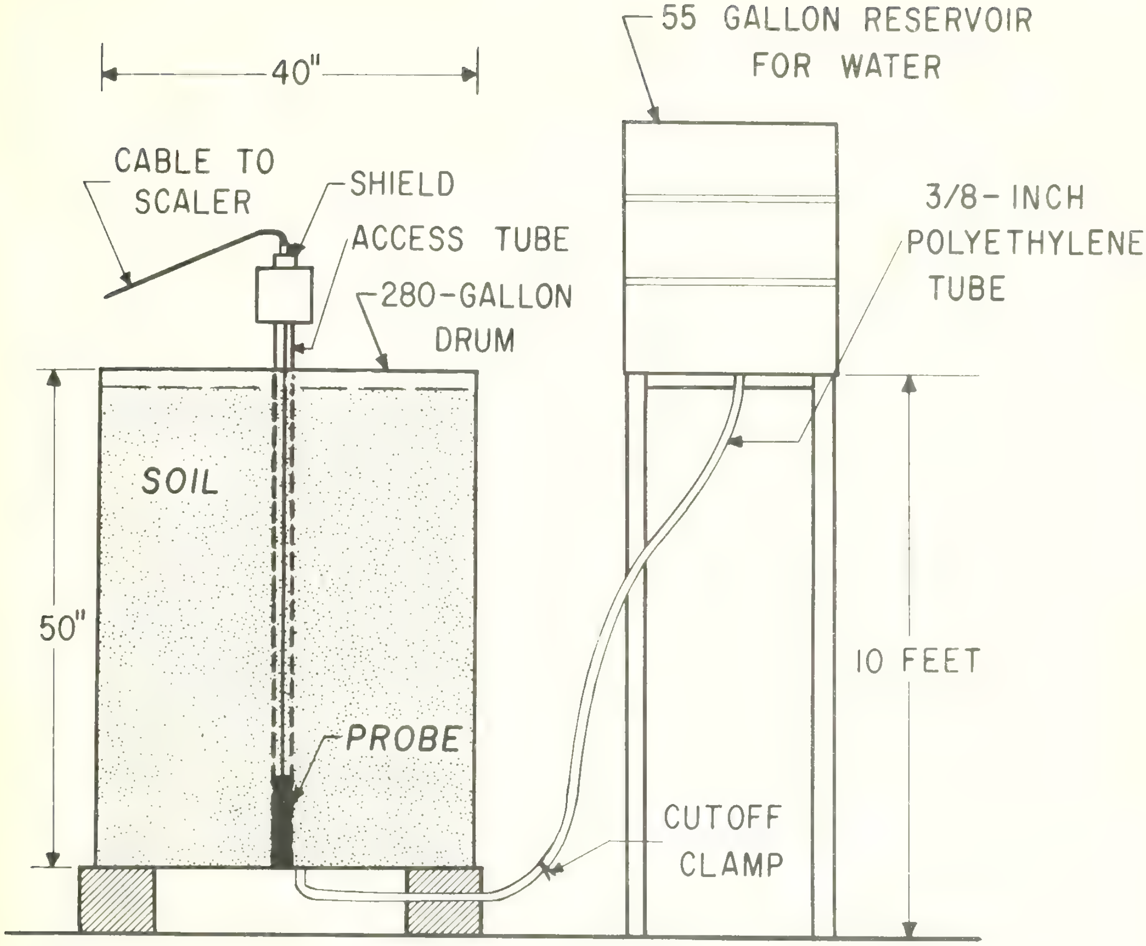

Figure 1.--Diagram of the arrangement of equipment used in calibrating a P-19 moisture probe by the water-addition method. The soil column is saturated from below under pressures up to 380 cm of water.

Soil-air interface effects were apparent at the top and bottom of the soil column, but within the center one-third of the drum variation in counting rate between 2-inch intervals was generally less than 1 percent by volume. Variation was attributed to slight differences in soil density and to small quantities of trapped air remaining after saturation. Count rates in the center one-third of the drum were used to calculate the mean change in counts. Since a uniform procedure was used in packing the soil, moisture changes throughout the drum were assumed to be uniform also.

This two-point calibration over a short range in moisture content assumes a linear relation between counts and moisture content. There is no reason to expect any other relation for probes of this design, since all reported curves are essentially linear between about 10 and 50 percent moisture. Also, previous gravimetric calibration of this particular probe gave a linear response throughout the moisture range studied.

RESULTS AND DISCUSSION

The b coefficients obtained by water-addition calibration appeared to fall into separate groups depending on mineralogy and texture of the soil fractions (table 1). Coefficients for the Cataula and Lloyd soils were not significantly different, and deviated from the mean by only ±2 counts per percent moisture volume. Variance among Appling sands appeared to be of about the same magnitude, but b coefficients differed significantly from those of Cataula and Lloyd series. If these coefficients were used to calculate moisture change, the error for either soil group would be less than 0.5 percent moisture for a change from saturation to approximately wilting point.

Table 1. --Calibration curve b coefficients for several Piedmont soils as measured by the water-addition method

Soil series	Texture	Horizon	b coefficient
			cpm
Lloyd	Clay	B	199
Cataula	Clay	B	202
Cataula	Sandy loam	C	202
Cataula	Sandy loam	C	204
Appling	Sand	A	238
Appling	Sand	A	241

Differences between b coefficients are attributed to greater neutron absorption by the Cataula-Lloyd series. The b coefficient for soils which are relatively efficient neutron absorbers will be less than that for inefficient neutron absorbers because these effects are proportional to slow neutron density. The b coefficient determined by the water-addition method contains the effect of absorbers, and since other factors associated with calibration are held constant, coefficient differences between soils can be ascribed directly to absorber differences.

Coefficients determined gravimetrically, by water-addition, and by the manufacturer differed appreciably (fig. 2). The discrepancy is attributed mostly to the failure of the arbitrarily selected drying temperature (105° to 110° C.) to remove all hydroscopic and crystalline water from the soil. The amount of water retained by soil after drying varies with texture and mineralogy of the soil fraction. The effect of tightly bound water is, of course, included in the counting rate, and its effect is appreciable in some Piedmont soils (table 2). Thus gravimetric calibrations derived from soils of varying textures will contain a positive but unpredictable bias. Moisture content changes based on calibration using arbitrary drying temperatures, although reproducible, may be in error by as much as 36 percent. It appears that the warnings against using more than one type of soil material to derive gravimetric calibration curves (6) are justified for two reasons: (a) They are customarily based on the removal of water from soils by arbitrary drying temperatures. (b) Even if such error were reduced by higher drying temperatures or adjustment, the neutron absorption characteristics of various soils, as demonstrated here, may still dictate separate calibration when precise results are needed.

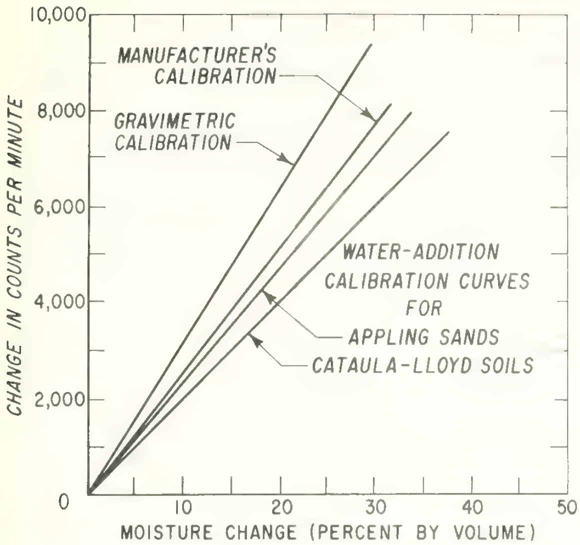

Figure 2. --Comparison of the effect of the b coefficient determined by two methods of calibration on calculated moisture change.

Table 2. --Slow neutron counting rate measured in 5-gallon containers filled with soil dried at 105° C.

Soil series	Horizon	Texture			Counting rate 1/
		Sand	Silt	Clay	
		- - Percent - -			cpm
Appling	A	87	9	4	26
Cataula	C	57	33	10	38
Cataula	C	66	17	17	42
Cataula	B	37	14	49	207

1/ Counting rate above background count.

SUMMARY

Measuring soil moisture changes from one time to another by the neutron method requires that the calibration slope coefficient accurately represent the change in count rate per unit change in moisture content.

A new method is presented which allowed a check on slope coefficients derived from gravimetric calibrations. Slopes were obtained experimentally for four Piedmont soils by the addition of a known volume of water to a known volume of each soil. The count rate per unit change in moisture content differed between Appling and Cataula-Lloyd series by about 17 percent, and the difference was attributed to neutron absorbing characteristics of the soils studied.

Coefficients obtained by water addition differed from those obtained gravimetrically by as much as 36 percent, depending on soil series. Differences were attributed to (a) bias arising because drying temperatures used in gravimetric calibration failed to remove all soil water, and (b) failure of the gravimetric method to account for neutron absorber differences between soils.

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A Revised Shortleaf Pine Bibliography

Compiled by

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Southeastern Forest Experiment Station

Asheville, North Carolina

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A Revised Shortleaf Pine Bibliography

Compiled by

Glenn P. Haney

Shortleaf pine, Pinus echinata, Mill., is one of the four pine species commonly referred to as southern yellow pine. It comprises about one-fourth of the total volume of pine timber in the South. Its botanical range extends from New Jersey to Texas and Oklahoma, occurring in some 22 states. Shortleaf pine is commercially important in the Piedmont region of Virginia, North Carolina, South Carolina, and Georgia; in the northern portions of Alabama and Mississippi; along the western foothills of the Appalachians in Tennessee, Kentucky, and West Virginia; and in eastern Texas, southeastern Oklahoma, southwestern Arkansas, and northwestern Louisiana. In recent years shortleaf pine has become an important planting species in southern Indiana, Illinois, and Missouri.

A bibliography was prepared covering the literature pertaining to this species from about 1900 to June 1954 and published as Southeastern Forest Experiment Station Paper 48. Since then, many new references have appeared. This revised edition brings the bibliography up to December 1960 and includes a few references omitted from the earlier publication. Forest Survey Releases from the Southern and Southeastern Forest Experiment Stations that contained data pertaining to shortleaf pine were omitted from this revision because they are outdated every few years. Unpublished theses have been grouped and listed alphabetically by author as a final section to the bibliography.

Information concerning shortleaf pine may be found in a wide variety of publications including technical journals, trade journals, and farm magazines. Some articles therefore are of a popular nature, while others are technical accounts of research studies. Readers with a general knowledge of the periodicals will be able to estimate whether treatment is technical or popular.

The subject matter divisions are rather broad in order to keep the bibliography as simple as possible. All citations appear in each division in alphabetical order by author.

In compiling this bibliography, a reference was not cited more than twice. For example, an article on the effects of fire on reproduction appears under the head Effect of Fire as well as under Regeneration. Tables of volume growth and yield appear under both Forest Management and Mensuration. Monographs on the species appear under General References.

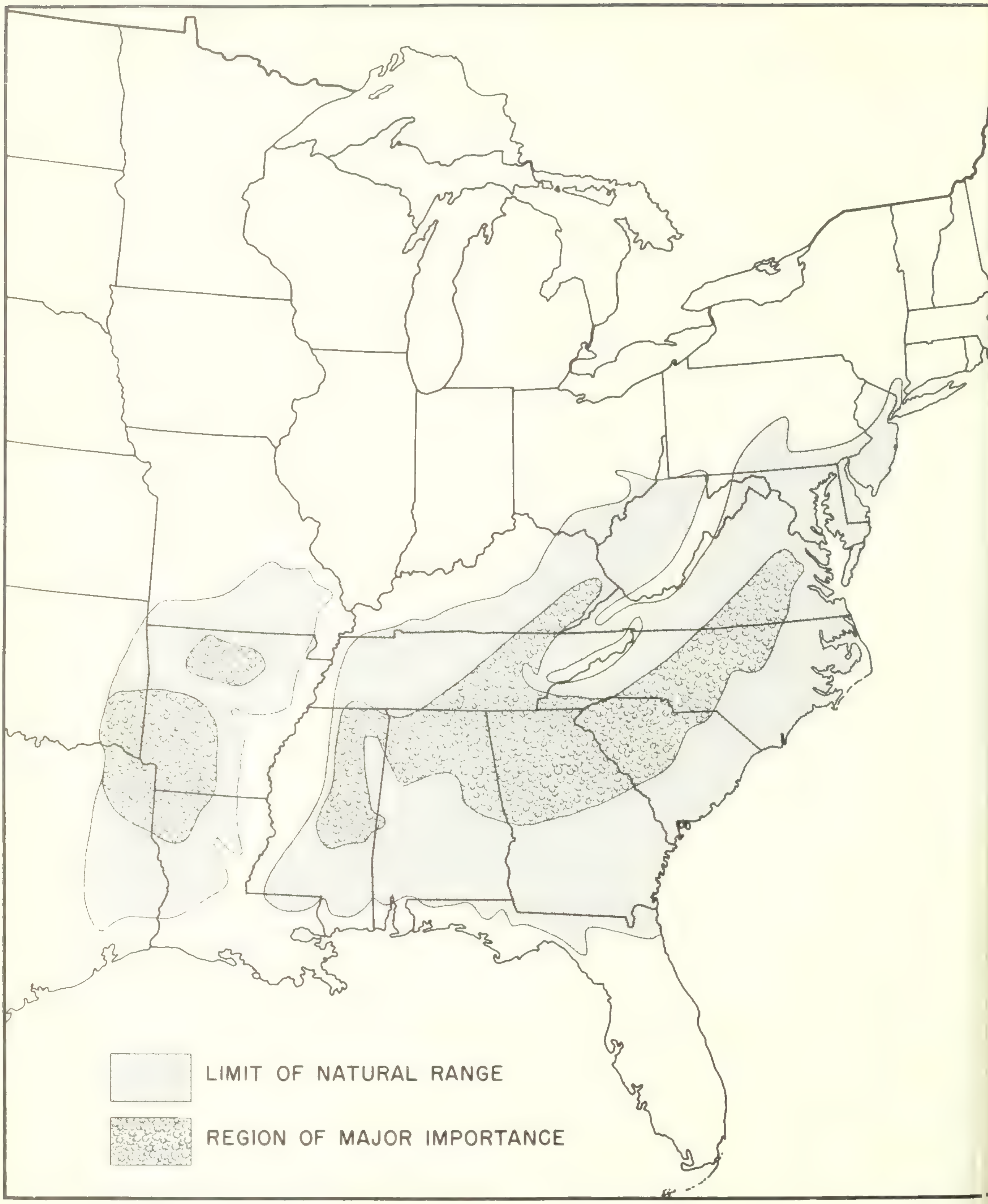

Figure 1.--Range of shortleaf pine, showing the limit of its natural range and its region of major importance.

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A Guide to Grading Features in Southern Pine Logs and Trees

by

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INTRODUCTION

The measure of quality of a log or tree is dependent on the products it will yield. For example, lumber is greatly affected by such gross characteristics of the tree as limbs, knots, conks, sweep, scars, etc.

This guide is offered as a help in understanding these characteristics and their effect on the type of lumber and 2-inch dimension material produced from southern pine logs. Specifically there were four major species studied: Slash pine (Pinus elliottii), loblolly (P. taeda), longleaf (P. palustris), and shortleaf (P. echinata).

Southern pine log grades 1/ have been developed during the past 15 years of study and have been approved for Forest Service use. This guide is supplemental to the grading system and is intended as an aid to the application and use of these log grades. Unless otherwise stated, the degrading and other features described in this guide apply over the entire commercial range of southern pine. The only end product to which the log grades and this guide apply is lumber, in the standard grades and sizes including 2-inch dimension, as defined by the Southern Pine Inspection Bureau. 2/ It does not include stress-graded material.

To apply log grades consistently and accurately, a buyer, seller, or other user must fully understand which of the surface blemishes is a log defect and how important it is. Blemishes have been divided into two major classes as follows:

1. Degrading features.
2. Non-degrading features.

The first category--degrading features--was established because the presence of one or more of these items in a log will lower its value when it is sawed into lumber. A good example is the large knot. The items in the

---

1/ Specifications are now available from the Southern or Southeastern Forest Experiment Stations in handy pocket form and are entitled, "Forest Service Standard Grading System for Southern Pine Yard Lumber Logs."

2/ See "Standard Grading Rules for Southern Pine Lumber," published annually by the Southern Pine Inspection Bureau of the Southern Pine Association, New Orleans, Louisiana.

second category, non-degrading features, do not degrade the log or tree even though they may reduce volume, as in the case of fire or lightning scars. Each of these categories is described and illustrated in the following text.

Many of the words used in log grading have a number of different meanings and usages, even within the field of forestry. In order to minimize confusion, the following basic definitions apply in this guide and in the log grade specifications the guide supplements.

A log degrading feature is an imperfection (usually visible on the surface) which lowers the quality of the lumber produced from the log. (In contrast, an imperfection in the lumber is called a lumber defect.) In southern pine these degrading features are limited to knots, conks, and excess sweep. Scaled deductions are made for rot and excess sweep but not for knots.

DEGRADING FEATURES OR IMPERFECTIONS

Most log imperfections are related to lumber defects in the underlying wood. Since lumber is the only product considered in these yellow pine log grades, the most important log imperfections are those which directly and consistently influence the quality of the lumber. They include all imperfections which relate directly to knots (lumber defects in the underlying wood), such as limbs, stubs, holes, overgrowths and unsound knots. They also include excessive sweep (as defined in the specifications), and wood-rotting hyphae. Even though scaling deductions are not made for log knots and overgrowths, they are made for rot, and for sweep if excessive.

The various log-surface abnormalities common to southern yellow pine are discussed individually and grouped in order of descending importance.

LOG KNOTS AND OVERGROWTHS

The term "log knot" is used to cover live limbs, dead limbs, stubs, and associated holes and overgrowths, rather than the lumber term "knot," even though we know that these imperfections will show up as knots in the lumber.

A limb is defined as a branch $\frac{1}{2}$ inch or larger in diameter growing from the stem of a tree. As used here it includes the stubs, holes, and overgrowths that follow the various stages of limb deterioration (fig. 1). Limbs, in this sense, are by far the most common and most important log defect found in southern yellow pine. Overgrowths are bark distortions showing definite breaks or alterations in the normal pattern of the bark. The most common are those associated with overgrown limbs or knots. These are usually circular in form and are sometimes called "puckers" (figures 2 and 3).

A limb, stub, or associated hole or overgrowth signifies a knot in the underlying lumber. Hence they are classed as degrading features--with the exception of adventitious limbs.

Although all limbs over $\frac{1}{2}$ inch in diameter are log degraders, their size influences their importance in log grades. Hence, it is necessary to recognize the types of knots and limbs and to standardize on measuring methods.

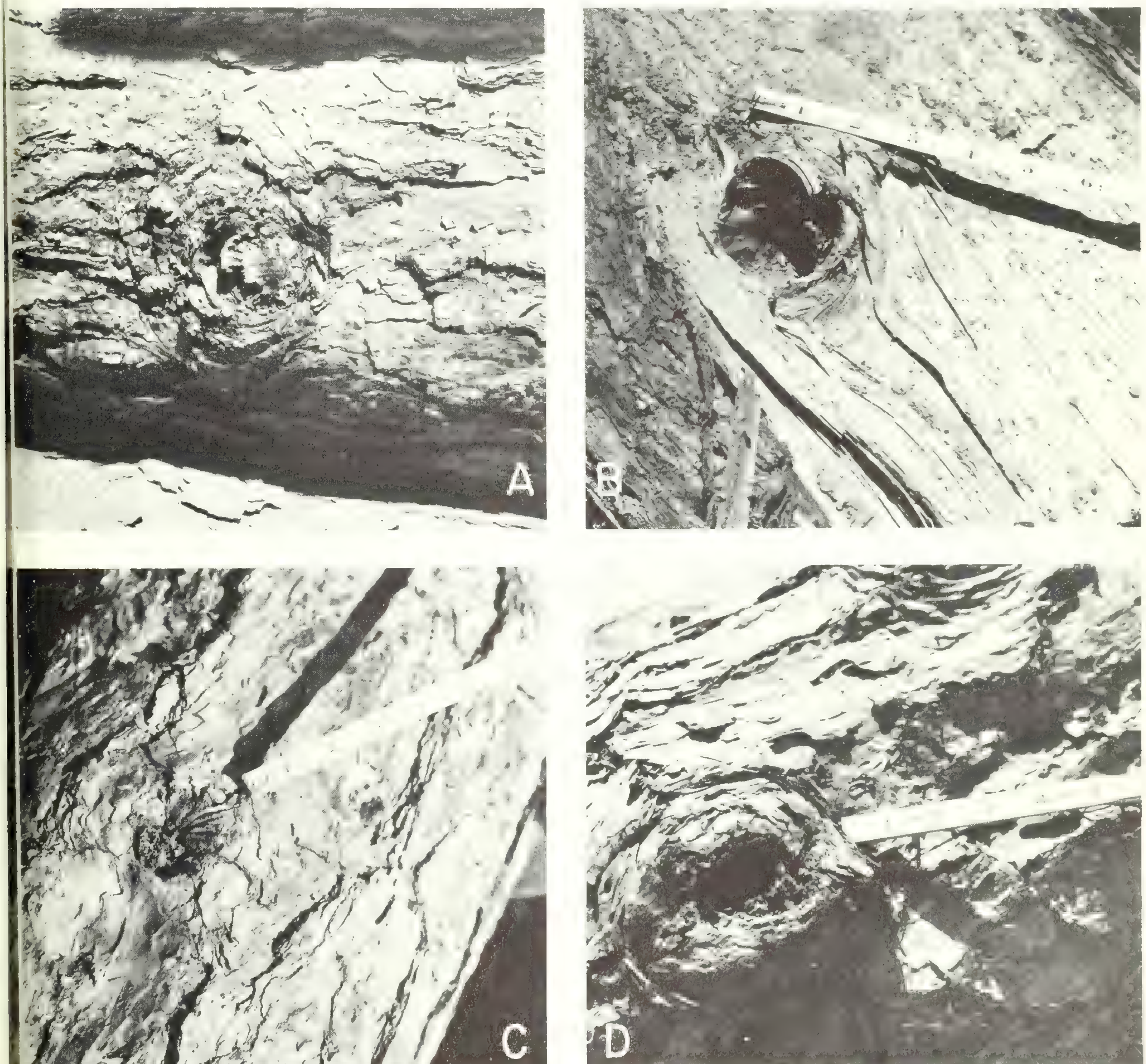


Figure 1. --Commonest degrading features are log knots. Here are examples of stubs and sockets. A shows a limb stub of recent origin. B is an old limb socket. C, new callus tissue forming around a limb socket. D, old callus growth around recently shed limb stub.

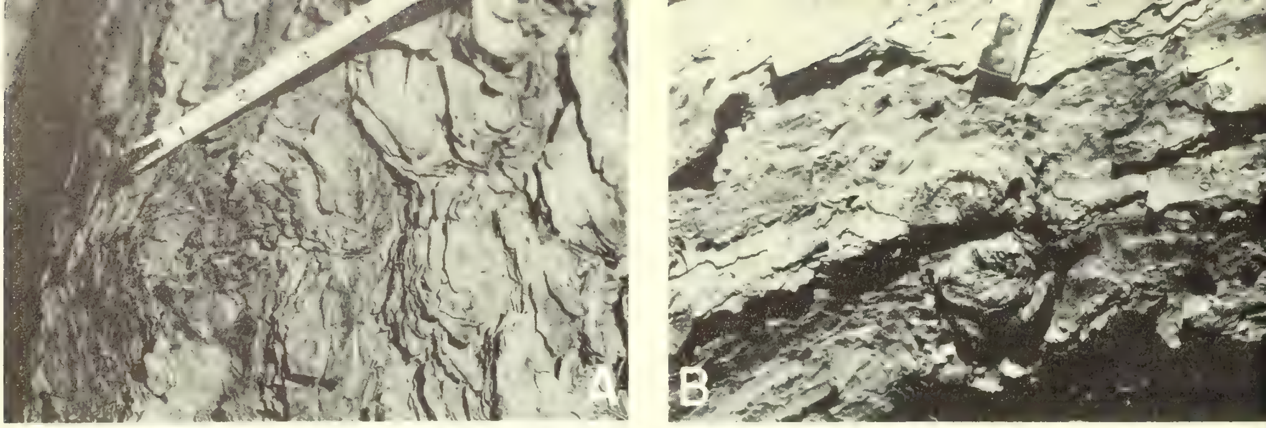


Figure 2.--Log knots showing up as overgrowths or puckers. A is an early-stage pucker. B shows a much later-stage overgrowth.

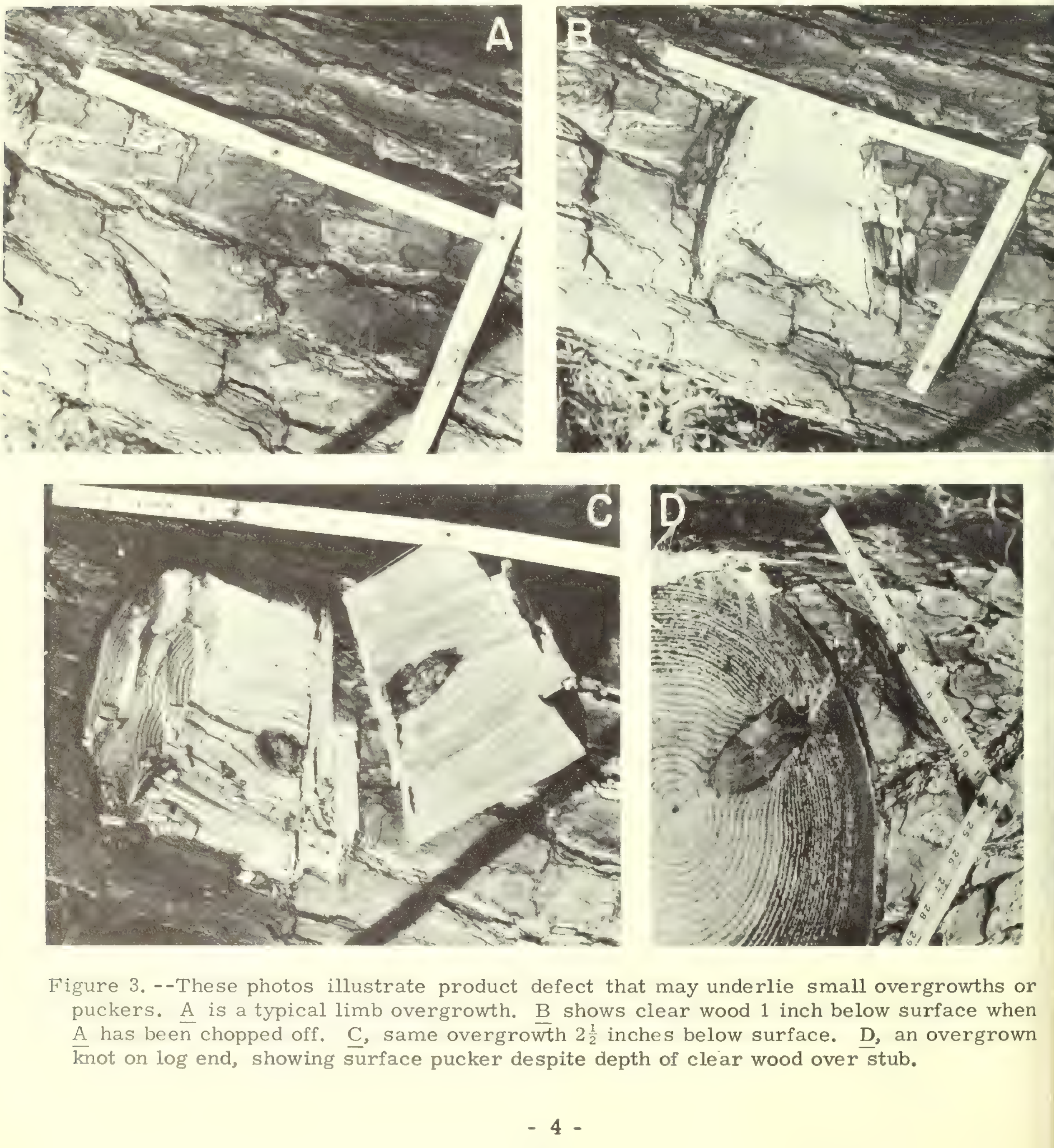


Figure 3. --These photos illustrate product defect that may underlie small overgrowths or puckers. A is a typical limb overgrowth. B shows clear wood 1 inch below surface when A has been chopped off. C, same overgrowth $2\frac{1}{2}$ inches below surface. D, an overgrown knot on log end, showing surface pucker despite depth of clear wood over stub.

Limb and Log Knot Measurements

Live limbs. --Measure the size of a limb near its junction with the tree trunk. Do not include the swelling commonly present at the limb collar. Measure limb diameter outside bark to the nearest inch (fig. 4). All live limbs $\frac{1}{2}$ inch and over are grading defects. Adventitious limbs (being smaller) do not degrade a log.

Dead limbs are generally measured in the same way as live ones. If, however, only a portion of the original limb stub remains and size is important, estimate its diameter (inside the surrounding callus tissue) to the nearest whole inch. Limbs or stubs unsound because of rotten sapwood are also measured or estimated as though sound--to the nearest whole inch (fig. 5).

Overgrowths are the remaining evidence on the log surface of a defect covered by callus tissue (fig. 2). Those with a characteristic circular bark pattern are frequently called "puckers" (fig. 3). These bark distortions are most commonly associated with overgrown log knots. Sometimes an overgrowth resulting from a logging scar or other damage will be irregular in shape, in contrast to circular ones covering old log knots.

Unsound log knots are either: (a) those with visible rot (which extends into the log), or (b) those surrounding a hole which extends two or more inches below the bark. Although they appear innocuous they usually indicate decay inside the log (fig. 6).

Oversize log knots are any sound log knots with an average diameter larger than 1/6 the scaling diameter of the log (fig. 7).

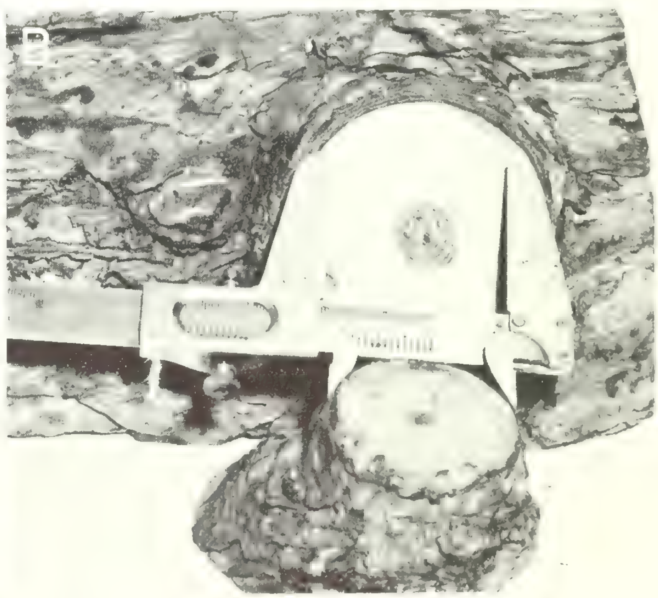


Figure 4. --Limb and knot measurement. A, live limbs are measured as indicated here, to the nearest inch of diameter; do not include the bark callus where limb joins trunk. B shows relation of limb size to trimmed knot size; hence if knot is measured after trimming, include only the surface area enclosed by circular annual rings and not all of the exposed wood.

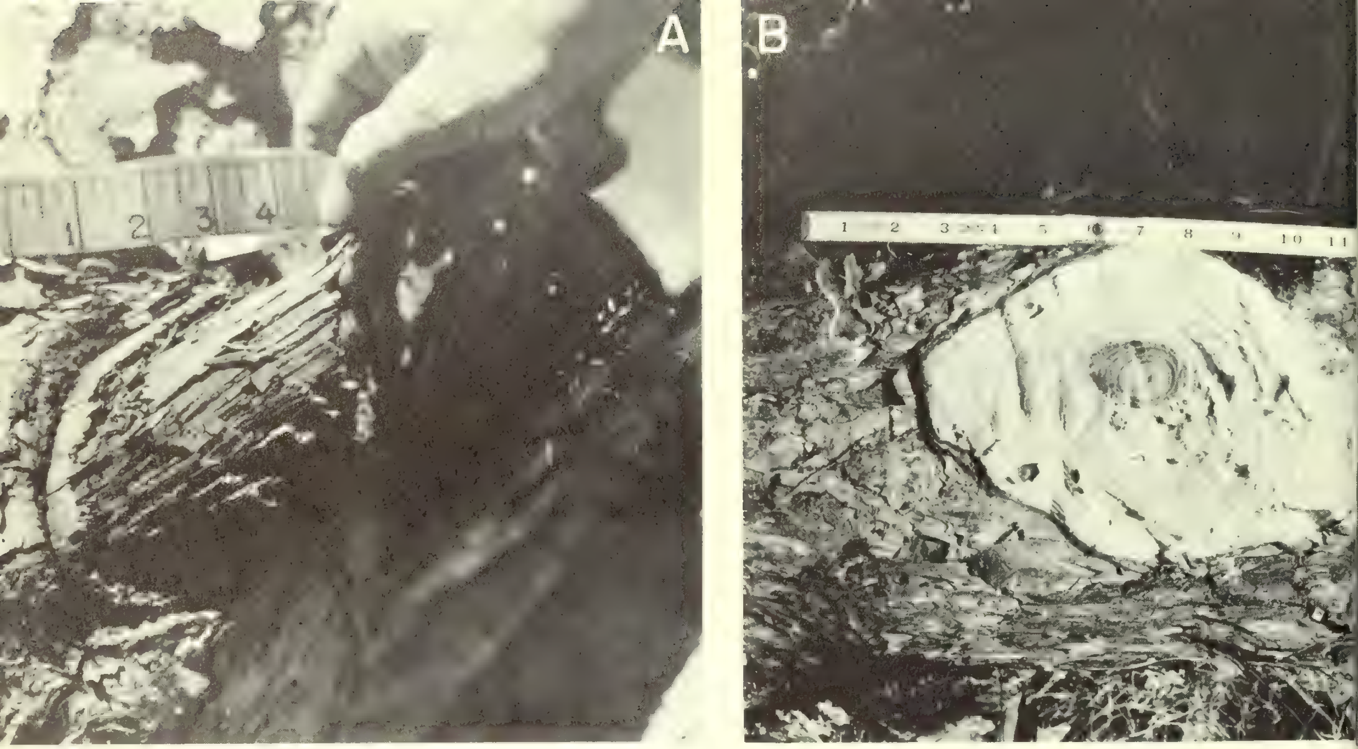


Figure 5. --Log knots resulting from dead limbs. A, sound limb stubs often appear rotten. B, when limb stub shown in A has been trimmed flush, note that all exposed wood is sound.

Multiple log knots are more common on old trees. They look like more than one knot, but sectioning will show them coming from one original limb which has callused over and resprouted. Only the largest sprout or branch is counted (fig. 8).

Holes, large. --A special kind of degrader resulting from bird damage is the large round hole. This item is discussed here since it is a degrading feature, whereas small holes can be ignored. Sockets are holes resulting from broken limbs, and, if large enough, are also classed as degrading features.

A large hole is an unoccluded opening larger than $\frac{1}{2}$ inch in diameter which penetrates through the bark and 2 or more inches into the wood of a tree. Common causes are rotten limbs, and woodpeckers or animals excavating infected spots in search of insects or a den. Within the range of the cockaded woodpecker (North Carolina to Texas) these birds will sometimes drill nesting holes in apparently sound trees. According to ornithologists, however, they usually choose to "hole up" in a tree already infected with red heart, where the drilling tends to be easier (fig. 9).

Most large holes occur in the upper part of a tree, at least above the butt log. Rot is usually associated with them, either as a cause or as an aftereffect. The hole itself is obviously a lumber defect. These holes are circular in shape, in contrast to the unsound knot holes, which tend to elongate with age.

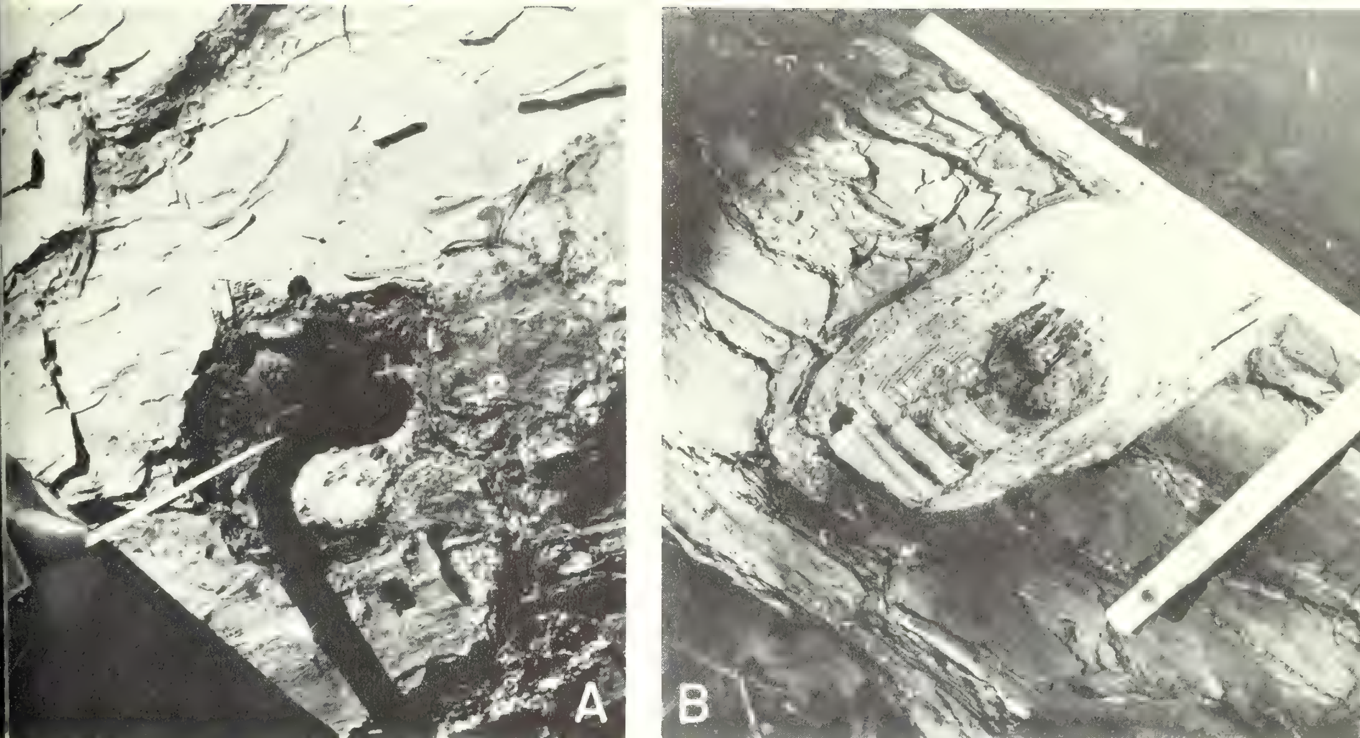


Figure 6. --Unsound knots are those with $\frac{1}{4}$-inch or larger hole penetrating 2 or more inches below log surface. Although they appear sound, they are usually rotten. A, depth and soundness should be tested by probing. B, as in A but 3 inches deep; definite decay evident.

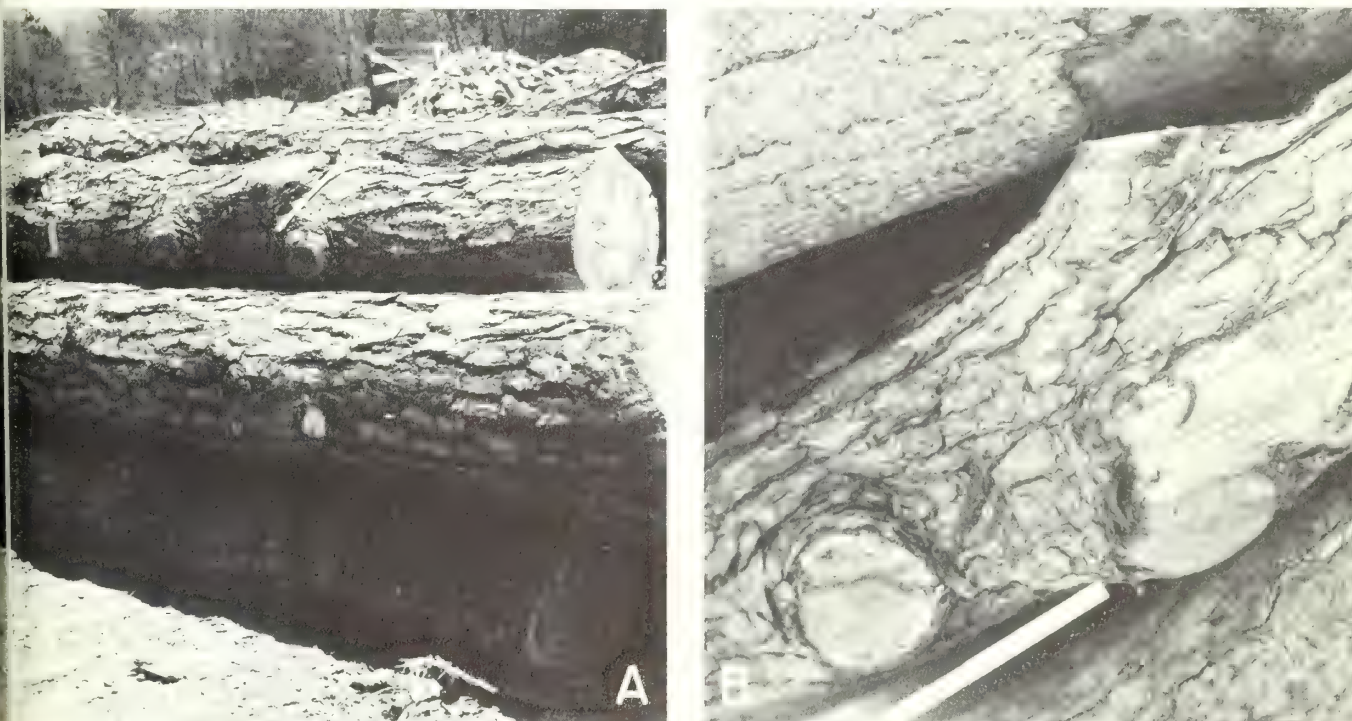


Figure 7.--Log knots are oversize when they exceed 1/6 log scaling diameter. A, oversize knots in center log reduce it from grade 3 to 4. B, closeup of degrade due to oversize knots.

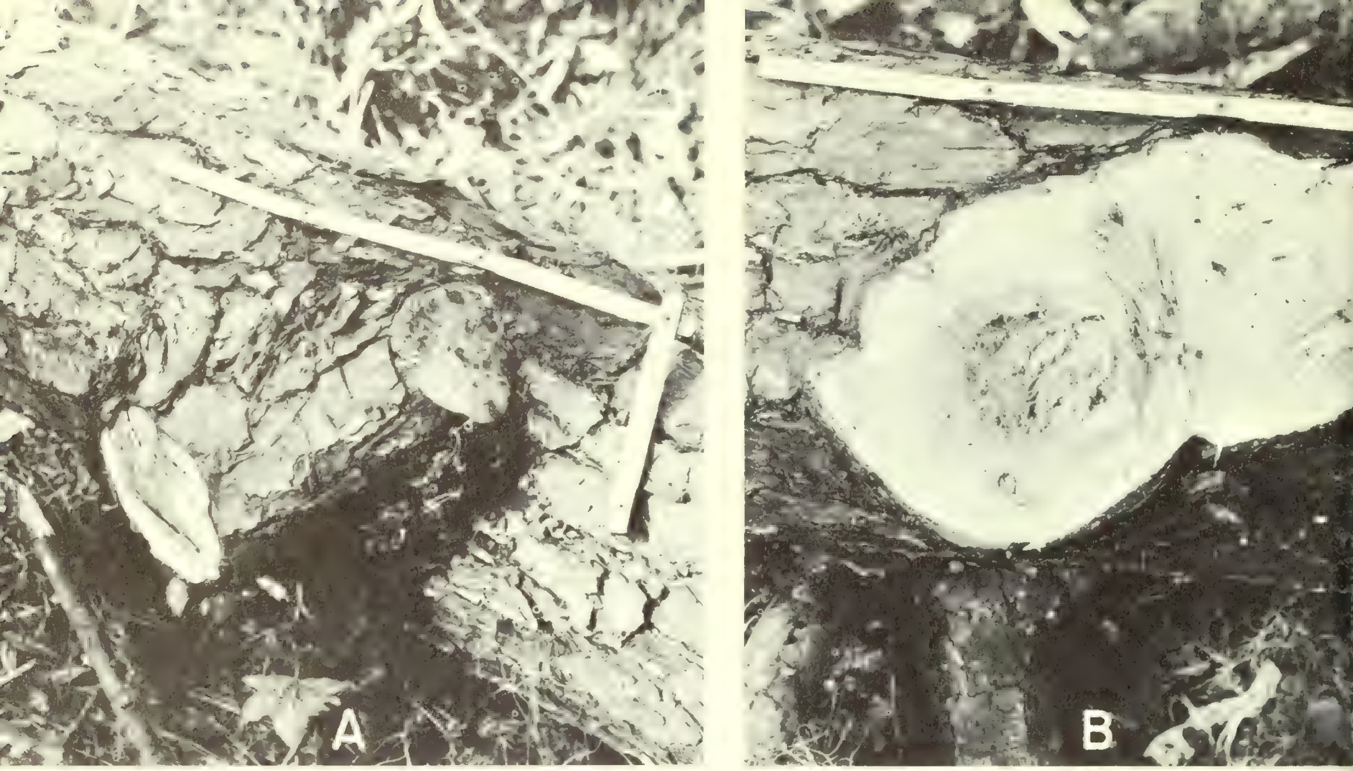


Figure 8. --A, a multiple log knot; the larger one only (on left) is counted or measured. B, the multiple knot at left opened up showing single knot effect on the lumber.

Figure 9. --Large holes are often animal caused. Those exceeding $\frac{1}{2}$ inch across and penetrating 2 or more inches below the log surface are a special type of log degrader. A, an example of a bird hole (woodpecker). B, slash pine with several bird holes (2 are shown); this type of degrader is serious but not common.

SWEEP (EXCESSIVE)

A gradual bend in a log or tree is called sweep, in contrast to a crook, which is an abrupt bend. Both originate when a tree is deformed by wind, snow, a falling limb or tree, or other mechanical cause, or when a tree suffers damage to its leader. They may also be caused by heredity. Sweep is specifically defined as the general deviation of the longitudinal log axis from a straight line connecting the geometric centers of the log ends (fig. 10). Sweep, in addition to being a scaling deduction if it exceeds the limits indicated below, results in a degraded log unless the log is already a grade IV.

When a sweepy log is sawed, the low-grade knotty core shows up in more boards than is the case with a normal log. The cross-grain effect weakens the lumber and creates machining difficulties. Compression wood, which is weak and surfaces rough, is also frequently associated with sweep. The net effect of serious sweep is lower-quality lumber due to the pith centers, cross-grain, low strength, and surfacing problems.

Proper log making in the woods can minimize the effect of sweep on quality. Sweep must equal or exceed 3 inches and 1/3 the log diameter to be called a log imperfection.

Figure 10.--Sweep, a frequent cause of degrade (if it exceeds 3 inches and 1/3 scaling diameter). A, in the tree, it can frequently be bucked out. B, in the log, it is too late for bucking to help.

CONK AND RED HEART

These are both forms of heart rot caused by the fungus Fomes pini (Thore) Lloyd. The conk is the fruiting body of the fungus contained within the tree (fig. 11A). It is a fibrous or fleshy protrusion of definite form and structure found on the bole of a pine tree. This fungus (and some others attacking yellow pine) gains entry through exposed heartwood, usually in broken-off or dead branches. Other evidence of this fungus is the punk knot--the knot with the nonfruiting fungus tissue (fig. 11B).

A conk signifies rot and the advance stage of decay. In yellow pine a conk usually marks a limb location, even if the limb is no longer visible. The extent of rot depends on the age of infection and the age of the tree. In any event, serious loss of volume and quality is indicated (fig. 11C), frequently to the point of rendering a log or tree unmerchantable. The presence of a fruiting body or punk knot piercing the bark surface of a log requires a reduction of one grade. Red heart alone without a conk or other signs is classed as a scalable item.

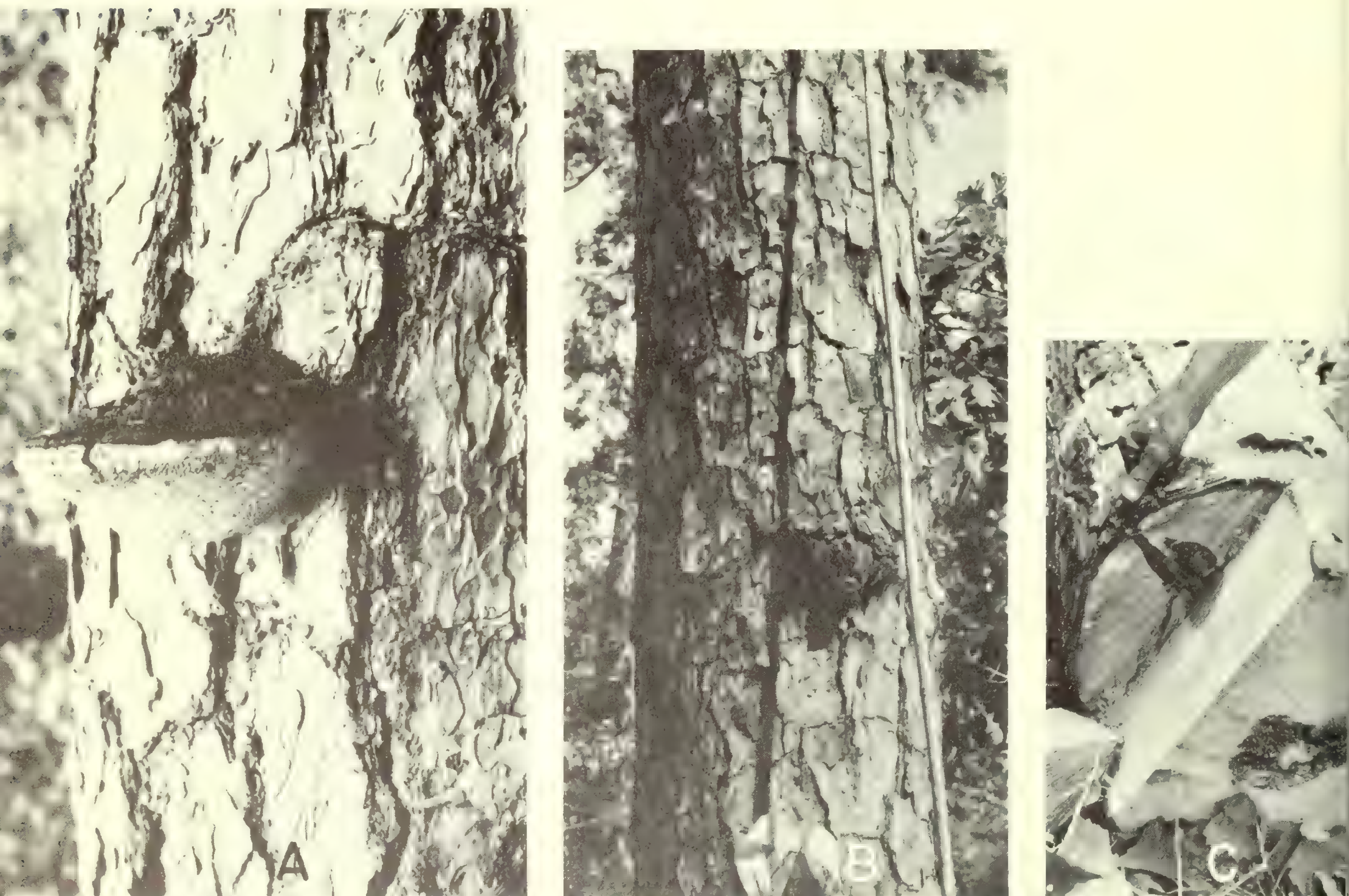


Figure 11. --Heart rot or red heart (Fomes pini) is always a degrader. Reduce log one grade when fruiting body or punk knot pierces bark surface. A, conk (sporophore) on trunk. B, punk knot--nonfruiting form of the disease. C, decay in the log; also shows probable access route through dead limb.

NON-DEGRADING FEATURES

In addition to the degrading features described above, other types of blemishes are classed as non-degraders. They don't lower the log grade but may lower the net volume. This group is further subdivided into scaled and non-scaled features.

Although not so vital in grading logs or trees as the degrading features, scaled features are still very important. Such items as cankers, scars from lightning, fire, or logging are included here.

SCALED FEATURES

Canker

A canker is a definite, relatively localized, partially open lesion, characterized in yellow pine by destruction and/or distortion of tissue, repeated callusing, and by pitch flow in varying amounts. The most common type of canker is cronartium. It and others sometimes serve as entry points for various rot-producing fungi.

A cronartium canker is easily recognized by the concave or "scooped-out" appearance of the lesion (fig. 12A, B). Accompanying lumber defects are due to the pitch (both massed and streaked) and to structural weakness from contorted grain.

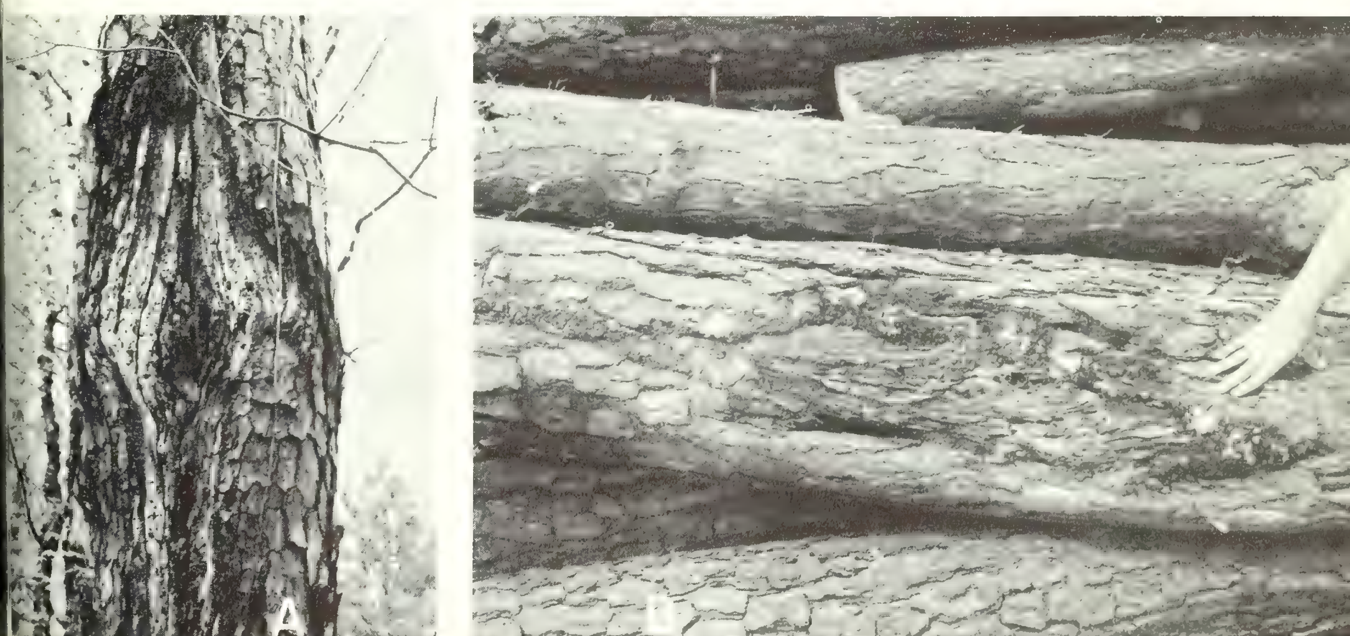


Figure 12.--Canker caused by Cronartium. A, as observed in the tree; a degrader in this case because rotten heartwood is exposed. B, not a degrader here because heartwood is not affected. Usually a canker is a scale deduction only.

Other types of cankers are less easily characterized. Some are of fungus origin, but they can also be caused by such things as frost, sun scald, and other wounds. Once an open lesion is produced, however, the entry of disease organisms frequently follows, and the typical pattern of tissue destruction and callus formation develops. Some cankers resemble burls or bumps, but the open nature of cronartium and the visible evidence of pitch flow indicate that it is a serious defect.

A cronartium canker by itself is a scaled feature, as are other cankers, regardless of size. However, it sometimes covers heart rot, which is a degrading defect.

Crook and Fork

Crook has already been mentioned, but is listed again here since it is a scaled feature (fig. 13). Logs are usually bucked so as to eliminate crook, especially if it is in two planes. Serious cases of crook are normally left in the woods as cull or are bucked into short lengths for cordwood.

Crook is normally scaled out of the gross log volume, and the remaining net volume is graded as though the crook were not there.

Figure 13.--Crook is especially serious if it exists in two planes. Because of cross grain and associated weakness, the affected portion is usually scaled out or left in the woods as cull material. A, crook in two planes in the tree. B, a crook in one plane is often left in the log despite scale deduction.

A fork is the portion of the log including parts of two or more tops (fig. 14A). Including a fork in the middle of a log is an operational error which sometimes results when logs are bucked to arbitrary lengths. On the other hand, some operators deliberately buck logs part of the way into forks (fig. 14B) in order to gain as much of the usable material as possible. Double pith and bark pockets are additional lumber defects associated with fork (fig. 14C). In the standing tree, a fork is considered to be either the end of merchantability or the beginning of a new log.

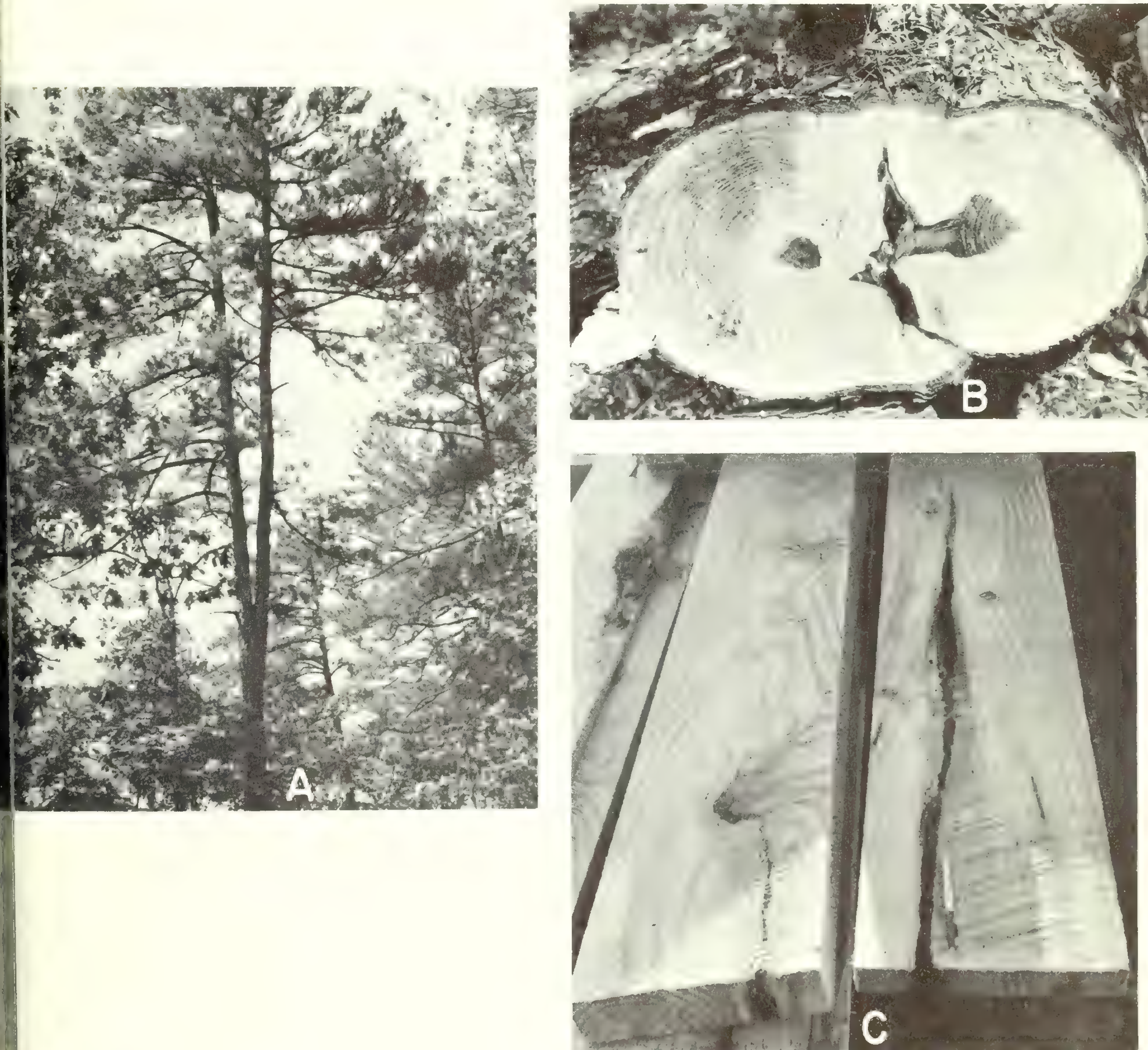


Figure 14. --Fork when left in the log, especially with included bark as in B, results in lower grade lumber. A, a fork as seen in the tree. B, fork with included bark. C, lumber from a fork as in B.

Injuries

Injuries are grouped here as biologically or mechanically caused, though it is sometimes difficult to distinguish between them.

1. Biological injuries included here are only those due to insects and those not already covered above (rot and canker).

Along with diseases, insects (figures 15 and 16) cause a great deal of damage to the southern pines. Sometimes Ips and Dendroctonus kill the tree outright within a growing season. In contrast, Ambrosia produce so little visible damage in trees or fresh cut logs (fig. 16A) that they are difficult to recognize. Losses caused by these insects can usually be scaled out, and are therefore listed as scaled features.

2. Mechanical injuries include shake (fig. 17A, B), splits (fig. 17C), and scars (fig. 18) or other logging damage. Most of this damage can be scaled out before the log is sawed into lumber.

Figure 15.--Examples of turpentine beetle damage. A, pitch globs are beetle entrance holes in the tree trunk. B, closeup of entrance holes. C, grub tunnels weaken the lumber.

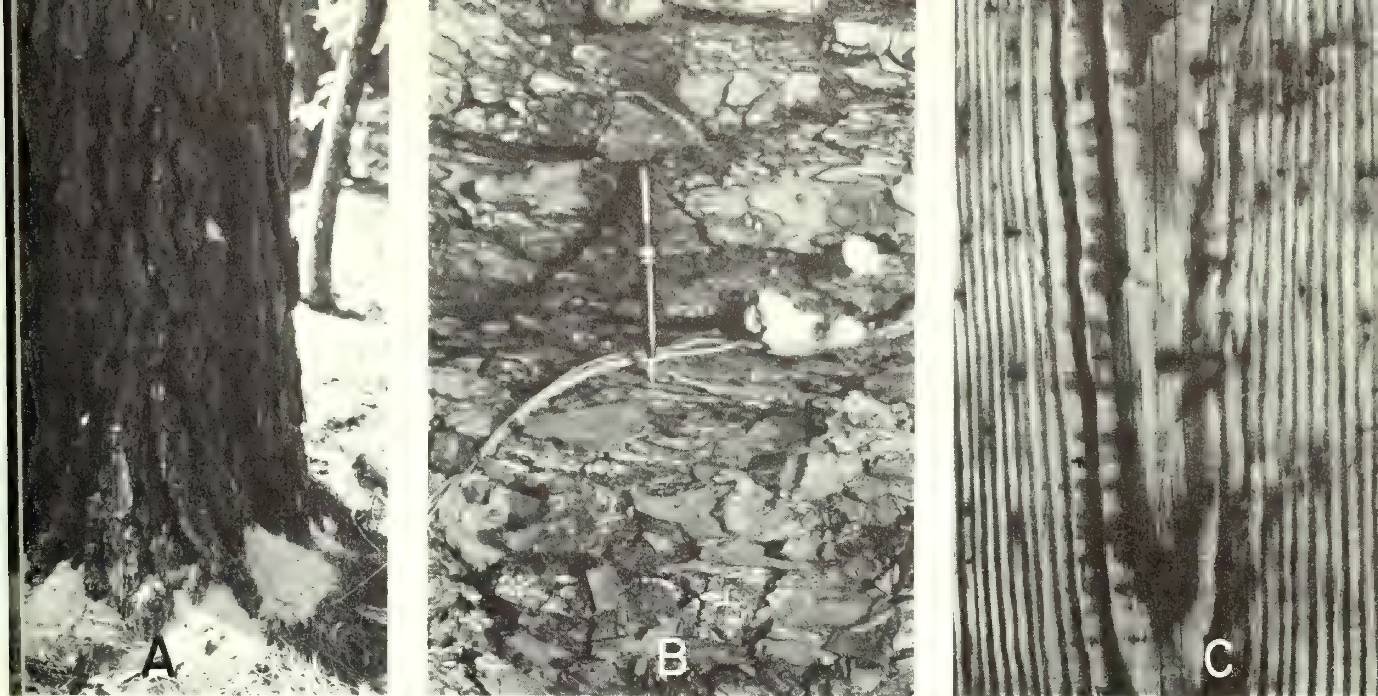


Figure 16. --Examples of Ambrosia beetle damage. A, the fine frass at base of tree indicates infestation. B, these insect holes are so tiny, they are easy to overlook in the log. C, their damage shows readily in the lumber.

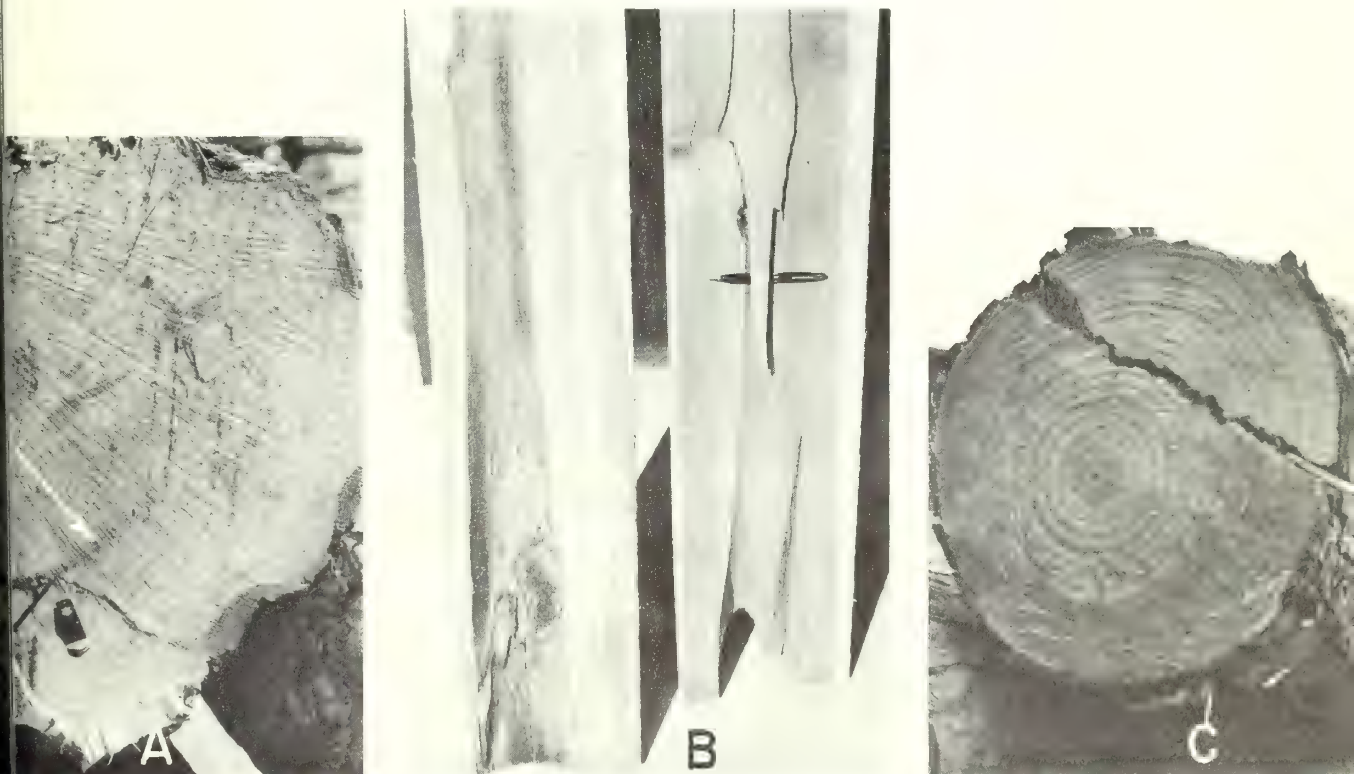


Figure 17. --Wind or ice damage can result in breaks in the log or tree which do not show up until the tree is felled, or sometimes until the log is sawed into lumber. A, observe shake at arrow tip. B, shaky lumber. C, split log.

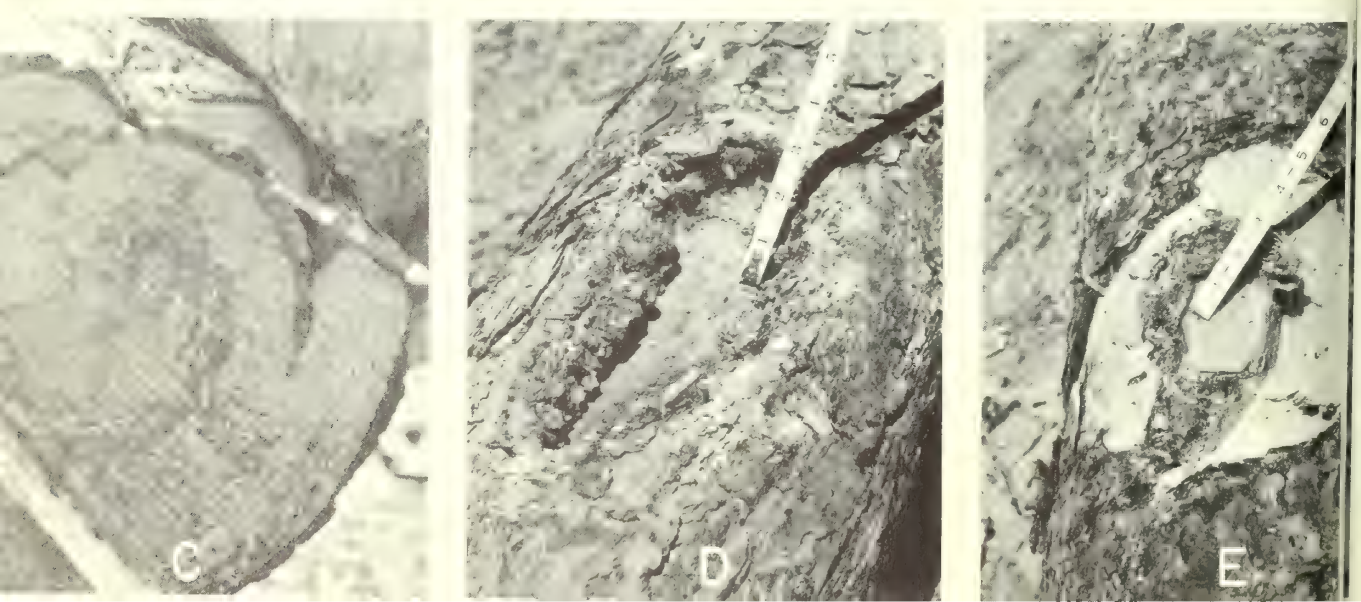
Shake is a scaled feature which cannot be properly estimated until the tree is bucked into logs. It is a scale deduction because the affected boards will usually fall apart.

Splits are another scaled feature. They are caused usually by careless or accidental felling. Sometimes they result from severe wind or ice damage. In any case, the damage may be scaled out, but improper sawing may result in serious degrade.

A scar is an opening in the bark exposing sapwood and sometimes the heartwood (fig. 18B). It is also used here to include the evidence of older wounds partially or completely covered over by callus tissue. Common causes are fire, lightning, falling trees or limbs, and past logging damage.

Scars commonly affect lumber value indirectly; that is, their degrading effect is likely to be from associated blue stain, pitch, rot, bird work, or insect holes.

Figure 18.--Scars are evidence of old wounds. A, lightning scar, obviously serious, but a scalable deduction. B, fire damage, when as serious as this, is often followed by insects and disease. C, D, and E, examples of old wounds, but note the sound wood underneath.



This type of blemish can be recognized on the log surface or end, but it either does not affect lumber quality, or methods of accurately estimating its effect on log grades have not yet been devised. This category has been subdivided into major and minor features. The major ones, while not common, are the more important in affecting subsequent lumber values, whereas the minor ones have little or no effect on the lumber. These minor ones, however, are frequently encountered. No scale deductions are made for either class of log defect.

Major items include compression wood, pitch soak, and stain. The minor ones are adventitious limbs, ripples, small holes, and swells. Most minor irregularities are removed with the slab.

Compression Wood

Compression wood consists of abnormal growth resulting from tree lean. Pillow and Luxford[3] have indicated that trees with five or more degrees of lean nearly always contain compression wood (fig. 19A). Compression wood is difficult to machine (fig. 19B, C). For this reason it is barred from the finish and stress grades of pine lumber.

It is a serious lumber defect, but to date there is no adequate measure of its effect on grade yield; hence, none on log grade.

Pitch Soak

This is a localized defect found mostly in the gum-collecting areas of Georgia and Florida (fig. 20). Furthermore, it is much less serious now than formerly, because of improved naval stores practices. While pitch soak is a lumber defect, causing degrade in the finish grades, it affects such a small volume and is so difficult to predict that it is not considered in grading logs or trees.

Stain

Stain differs from rot in several ways. The principal difference is that it does not reduce the strength of the infected piece. Stain is not considered a defect in fresh logs. It is chiefly encountered around wounds. Except in logs and trees left in storage too long before sawing, it is of very minor importance.

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[3] Pillow, M. Y., and Luxford, R. F. Structure, occurrence and properties of compression wood. U. S. Dept. Agr. Tech. Bul. 546, 32 pp., illus.

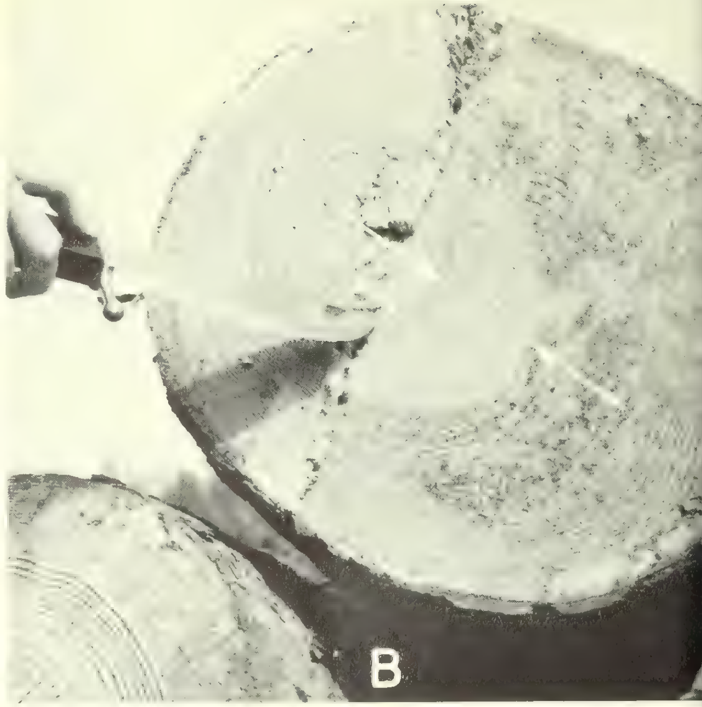

Figure 19.--Compression wood is found in leaning and crooked trees. Ways to measure and express this lumber defect in the log and tree are being studied. A, an example of a leaning tree with compression wood. B, compression wood as it appears in the log. C, such lumber is difficult to surface and store.

Figure 20. --Pitch soak is neither a log degrader nor ordinarily a lumber defect, but it does lower the lumber value in the finish grades. A, wood chipped face, formerly a common source of pitch soak. B, lumber containing pitch soak (dark portion of the board).

Adventitious Limbs

These are small limbs (less than $\frac{1}{2}$ inch in diameter) found on tree trunks below the normal crown (fig. 21). They do not have a heart center that extends to the pith of the log. They are more common on shortleaf than on the other four major southern pines. They frequently form on the trunks of trees following a heavy thinning or other opening operation. Under present marketing conditions, adventitious limbs are minor log defects, but this may well change if a pine veneer market develops.

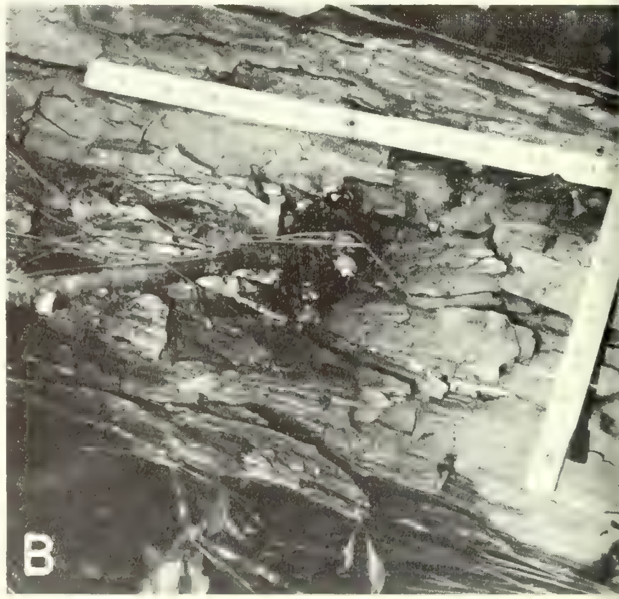

Figure 21.--Adventitious limbs (those under $\frac{1}{2}$ inch in diameter) found below the normal crown; ignore in grading. A, shortleaf tree with adventitious "feathers." B, slash or longleaf "feather." C, same as B, just under bark. D, same as C, $1\frac{1}{2}$ inches under bark; note wood still is clear.

Bumps and Ripples

A bump is a protuberance on a log surface, covered or partly covered with wood and bark. Although it is usually rather small, a bump may occasionally cover an area 10 x 20 inches on a large tree. It is usually smoothly covered over, but may be partly open and exuding a little pitch. It can be defined as a surface abnormality that is clearly not a burl or a limb overgrowth.

In old open-grown yellow pine, bumps sometimes indicate an overgrown limb stub or a deeply buried knot. They are more likely to be associated with healed over, deeply buried scars, although a damaged or mangled limb when overgrown sometimes appears as a bump on the log surface. When several bumps occur on the same log, they may be more serious individually than if only one bump were present.

Ripples, in contrast to bumps, are usually numerous and provide a wave effect in the surface of the log or tree, as illustrated in figure 22A and B. They can be ignored in grading.

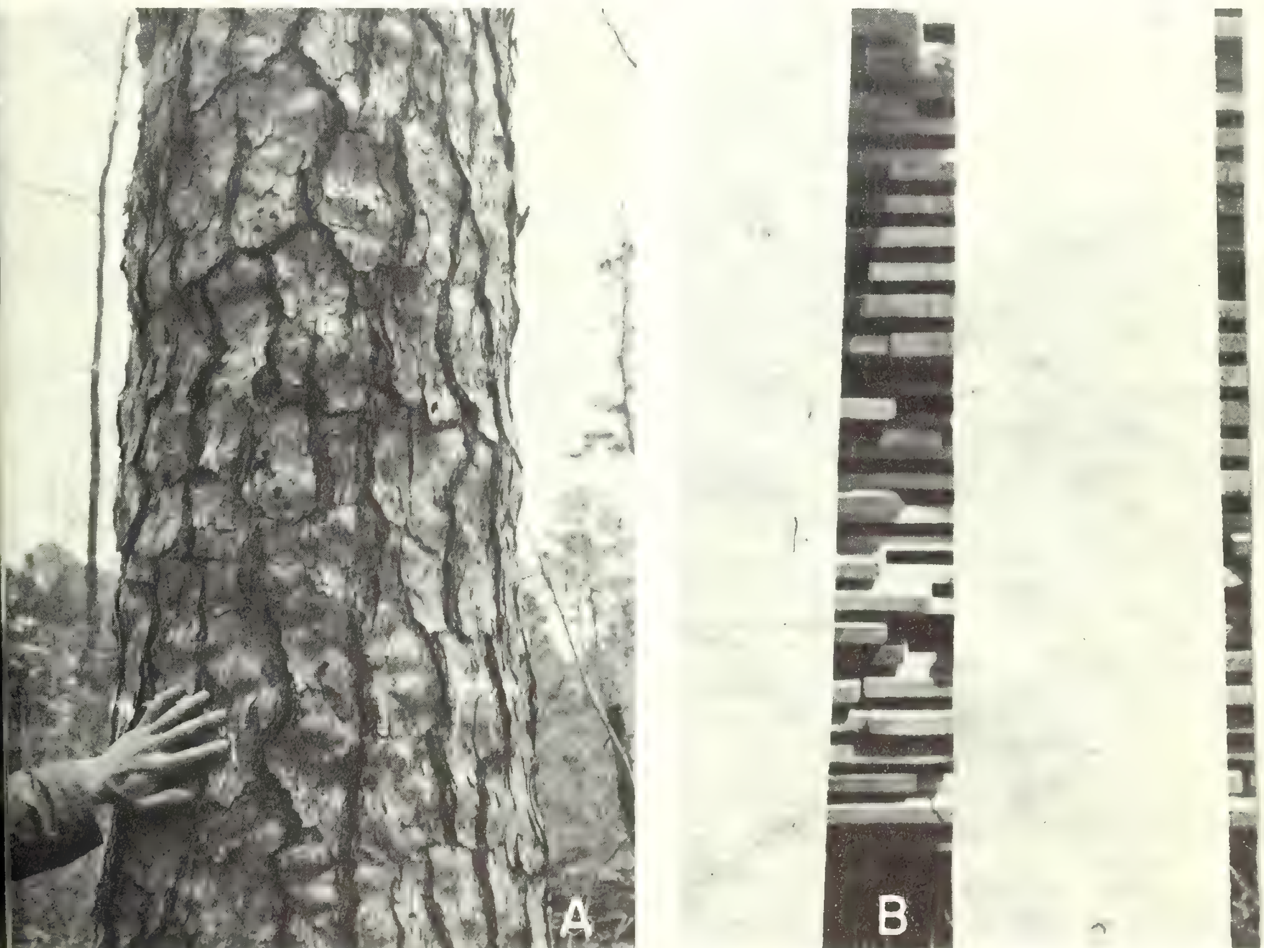

Figure 22.--Ripples provide a wavy effect in the log surface; they are ignored in grading. A, as seen in the tree. B, figured lumber from same tree.

Holes, Small

A small hole is an unoccluded or partially overgrown opening in the bark (not in a log knot), $\frac{1}{4}$ inch in diameter or smaller, which extends less than 2 inches into the wood of a tree. It is commonly caused by birds seeking insects in the tree bark, or by sapsuckers (fig. 23).

The small holes made by sapsuckers are usually confined to the bark, although they occasionally penetrate the wood slightly. They are usually found in horizontal bands or rows, but an occasional log may be freckled with them. They may produce small grain distortions or "bird's-eyes" in the lumber. Only rarely do dark, stained spots appear; this is in marked contrast to hardwoods, where associated stain and pockets of callus tissue are a major problem. When sapsucker attacks are severe, pitch flow may occur and pitch-related lumber defects may develop.

Swells

Neither butt nor stem swell in southern pines is common. This condition is usually caused by fire, or mechanical injury such as logging damage. Sometimes decay will cause an abnormal swelling on the stem. The causal agent is usually evident and the unsound volume, if any, can be scaled.

A flange is a protruding buttress-like structure at the base of a tree, extending outward beyond normal butt-flare or stump-flare. A flute is a convolution or fold running up and down the surface of a tree, but generally confined to the butt log. Neither is very common or important in yellow pine.

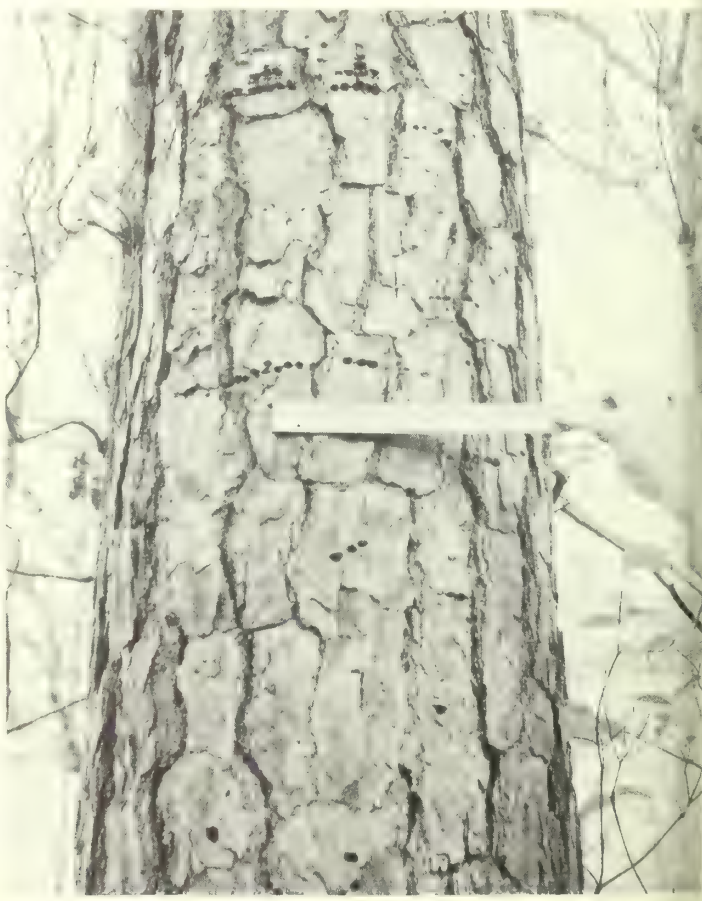

Figure 23. --Small holes such as these bird pecks can be ignored in grading.

SUMMARY

The chief grading factors used in determining the quality of southern pine logs and trees are diameter, straightness, and certain other external characteristics, especially knots, which indicate presence or absence of internal blemishes controlling product yield and hence the average value of the log or tree.

These "other characteristics" are classed as:

Degrading	Non-degrading
Knots (and large holes)	Scaled features cankers crook and fork insect and mechanical injuries
Excess sweep	
Conks (and red heart)	Features not scaled compression wood pitch soak and stain adventitious limbs ripples holes - small swells

The degrading features are the critical ones in grading logs and trees. Although the scaled items among the non-degrading are important economically because they reduce usable volume, their presence on a log or tree is insufficient cause for degrading it. The remaining not scaled but listed features are mentioned only because most of them are fairly common and their importance to grading is frequently questioned. All these items are pictured or described.

Softwood log and tree grades are still evolving; hence studies now in progress will provide further and more accurate information.

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